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INDIVIDUALIZED SCIENCE INSTRUCTIONAL SYSTEM

GETTING ENOUGH OXYGEN

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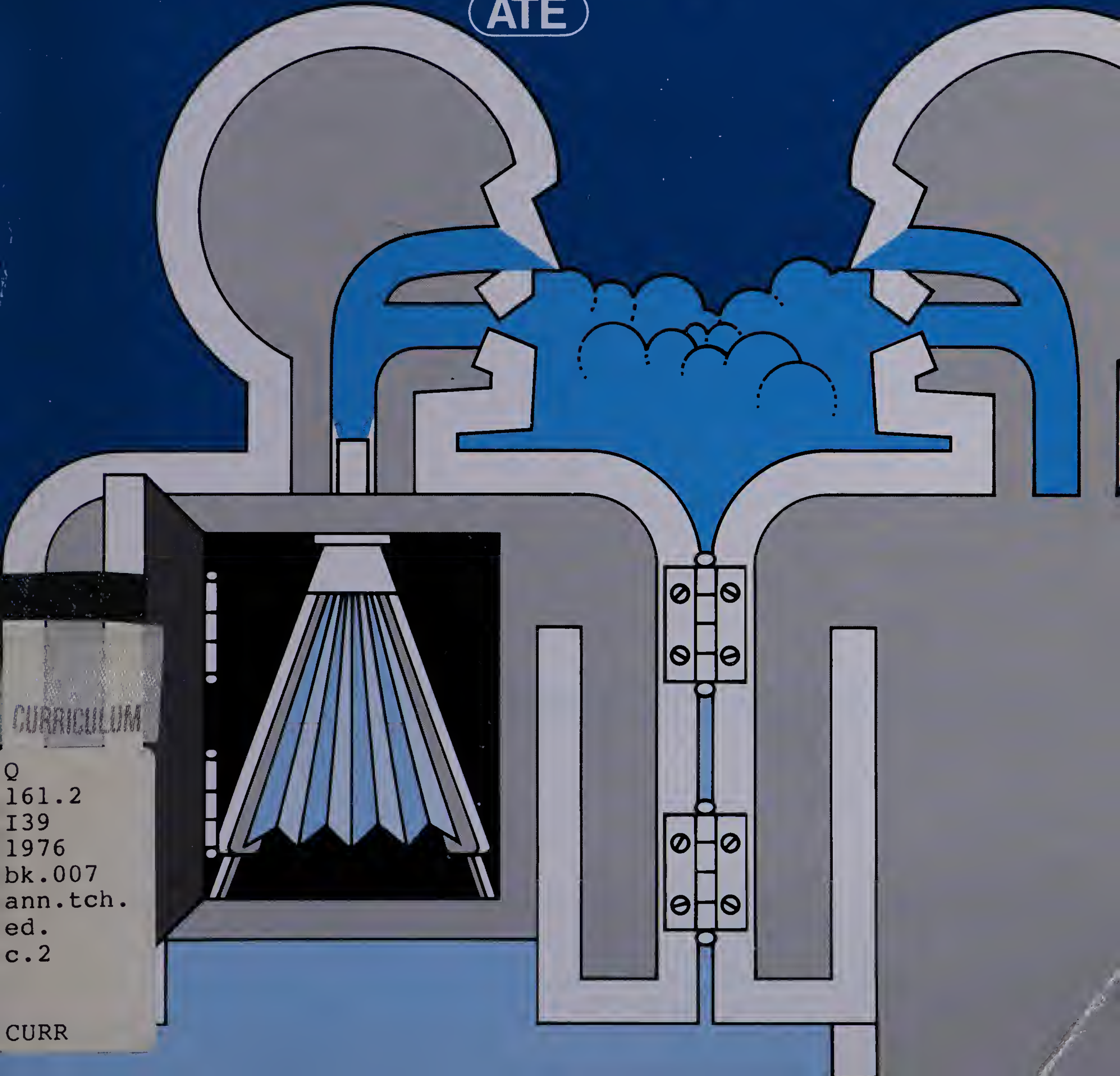

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INDIVIDUALIZED SCIENCE INSTRUCTIONAL SYSTEM

GETTING ENOUGH OXYGEN

ANNOTATED TEACHER'S EDITION

Ginn and Company

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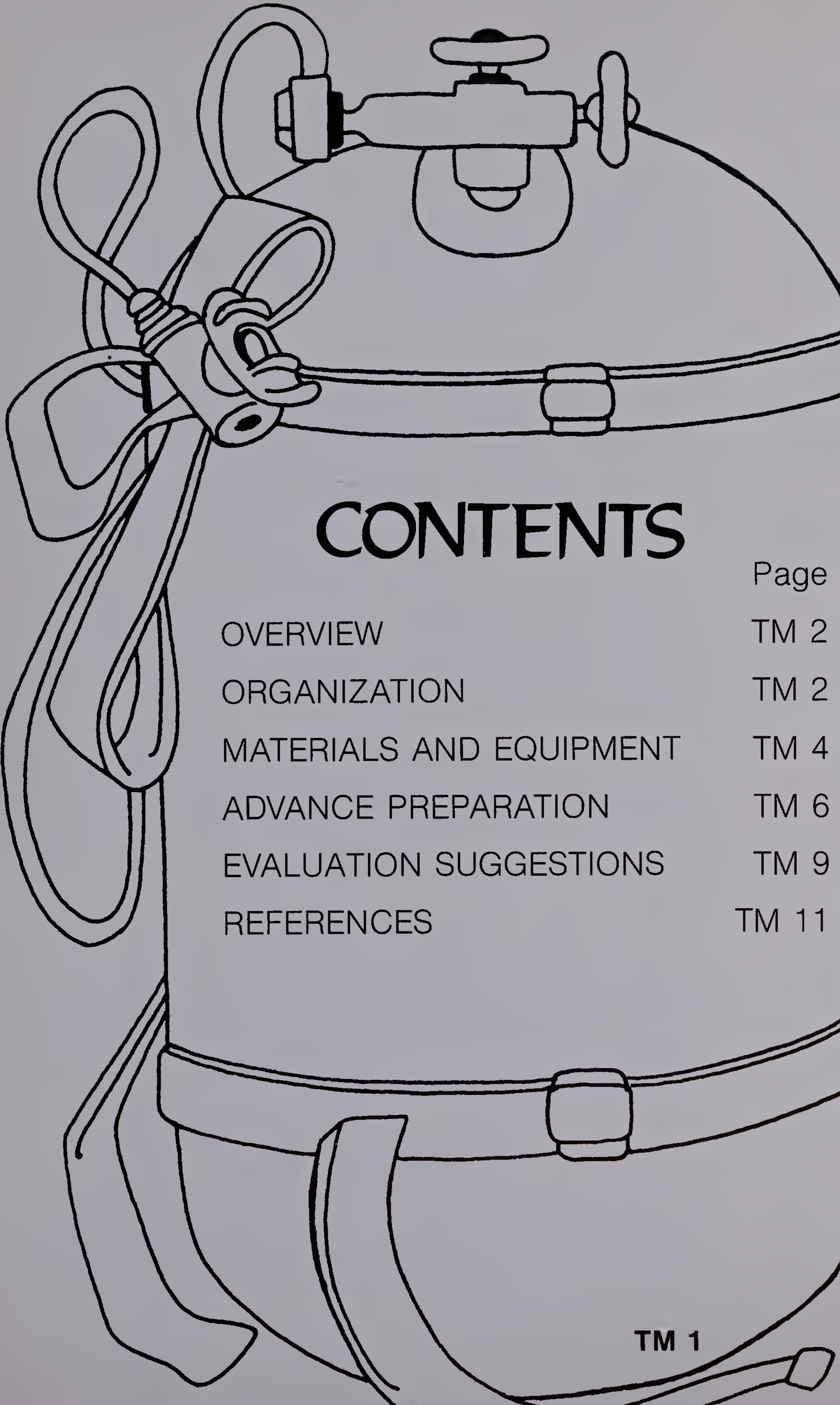

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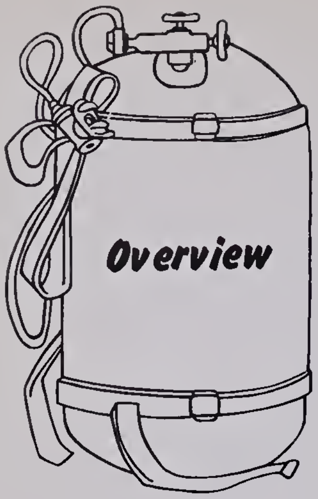


The record for voluntarily holding one's breath is about six and one-half minutes. For the average person, deprivation of oxygen for this long a period would almost certainly cause loss of consciousness, probably brain damage, and possibly death. Oxygen is vital to all known life forms.

Getting Enough Oxygen deals with the anatomy and physiology of the human breathing system, with the process of cellular respiration, and with the role of oxygen in terms of human survival. Useful information is included on common respiratory afflictions. Underwater breathing problems provide a backdrop in several activities, and hyperventilating before swimming is cautioned against as a potentially dangerous, sometimes fatal, practice.

This minicourse contains eight activities in the core section, three in the advanced section, and five in the excursion section. The planning activities must be done first in each section. In addition, any students who find that they need to do Activity 2 should do it before the other core activities. Activity 2 gives an overview of the human breathing system and introduces the terms needed for understanding subsequent activities.

The core activities focus on the mechanics and autoregulation of the breathing system, gas transport and cellular respiration, breathing emergencies, and unhealthy respiratory conditions such as pneumonia and emphysema. The mouth-to-mouth resuscitation technique is described in some detail and is of great practical value.

The topic of cellular respiration is taken up in more detail in an advanced activity. A second advanced activity deals with Boyle's Law — the relationship between the pressure and volume of any gas at constant temperature. Air held in the lungs is an example of this, and problems in underwater swimming and diving provide cases in point.

In the excursion activities, students may look into the causes of drowning or of such underwater diving problems as air embolism and the bends. Students may also choose to learn what part the breathing system plays when they hiccup, laugh, cry, sob, or sigh. Another excursion goes into the ways by which organisms such as insects and fish get enough oxygen.

Cassette Tape

The tape for *Getting Enough Oxygen* is an integral part of the minicourse. The tape has three bands, supplementing Core Activity 8 and Excursion Activities 13 and 14 in the student booklet.

The bands for Activities 8 and 13 constitute the major source of information for those activities; the questions in the student booklet are based on the taped information. A summary of the contents of each band follows.

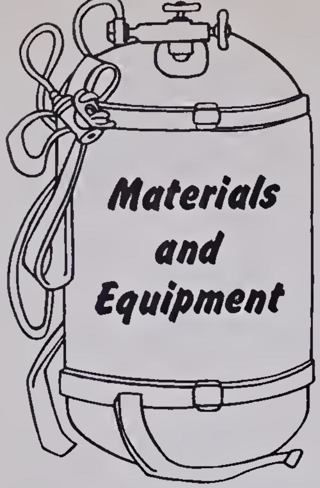
The tape band for *Activity 8: Getting to Your Cells and Back* is a description of how the body meets the needs of its cells by supplying them with oxygen and by getting rid of their waste carbon dioxide. Illustrations in the student booklet provide a visual path for the student to follow while listening to the taped information. A breath of air is followed into the lungs, through the alveoli, bloodstream, and heart, to the body capillaries and body cells, then back again as it becomes an exhaled breath. The process of diffusion is also described.

The tape band for *Activity 13: Overcoming Diving Problems* contains a dialogue situation in which three young scuba divers experience common diving problems due to the unique conditions of pressure found underwater. Drawings in the student booklet illustrate the main events of the taped story. The causes, effects, and prevention of the bends and air embolism are discussed. An optional activity described on the tape has students observe the phenomenon that causes the bends — a gas dissolving in and then bubbling out of a liquid.

The tape band for *Activity 14: Hiccups and Other Sounds* is a collection of sounds caused by different actions of the respiratory system. Students choosing Excursion Activity 14 are referred to this band of the tape for fun, to try to identify the various sounds heard. The sounds, which are not always obvious in definition, include hiccups, sighs, yawns, sobs, coughs, sneezes, and laughs. Some of the sounds are in "slow motion." And there may be some confusion between the laughing and crying, emphasizing that those sounds are caused by similar actions of the breathing system.

Diagnosis Game

The game *Diagnosis: Getting Enough Oxygen,* supplied separately, is used with Core Activity 4. The game consists of Rules, a Memory Card, and 9 Patient's Cards. Students play the game in pairs, with one student acting as the doctor and one acting as a patient. During the course of the game, which takes two or three class periods, the students become aware of some of the symptoms and treatments for several diseases of the respiratory system, including the common cold, pneumonia, bronchitis, and emphysema. Students should be reminded on completion of the game that they have not become doctors, just better-informed laypeople.



Materials and Equipment

The following chart represents an estimate of needs based on "student units." The student unit may be one student working alone, two students working as partners, or several students working as a group. The size of the student unit will depend on the nature of the activity and on the availability of materials and equipment.

QUANTITY PER STUDENT UNIT	ITEMS	ACTIVITIES			NO. UNITS THAT CAN SHARE
		Core	Advanced	Excursion	
	Consumable				
1	*Bag, small paper, 1-litre	7			
5 g	Calcium hydroxide, to make 1 litre of limewater	5			
0.5 litre	*Soda water, or other carbonated liquid (optional)			13	
1	*Straw, soda	3,5			
1 roll	*Tape, cellophane	3,5			
1	Tongue depressor	2			
	Nonconsumable				
1	*Bucket, 8-litre or larger	3			10
1	*Cassette player, preferably with headphones	8		13,14	10
1	Cassette tape for *Getting Enough Oxygen*	8		13,14	10
1	Cylinder, graduated, 100-ml	3,5			5
1	Diaphragm apparatus	3			15
	*2 large balloons				
	†bell jar				
	*small cork				
	*2 rubber bands				
	rubber sheeting				
	1-hole stopper, rubber or cork				
	*string				
	Y-tube				

*Items that can be obtained locally.

†A bottomless gallon jar of glass or clear plastic may be used in place of the bell jar.

Materials and Equipment (Continued)

QUANTITY PER STUDENT UNIT	ITEMS	ACTIVITIES			NO. UNITS THAT CAN SHARE
		Core	Advanced	Excursion	
	Nonconsumable				
1	Game *Diagnosis: Getting Enough Oxygen*	4			15
1	*Jug, translucent plastic, 4-litre (1-gallon)	3			5
1	*Mirror, small	2			5
1	Pencil, grease	3			10
1	*Penlight or flashlight	2			5
1	§Pressure-volume apparatus		11		15
1	Respiration apparatus	5			10
	2 Erlenmeyer flasks, 125-ml				
	2 rubber stoppers, 2-hole, #6				
	tubing, glass, 5 mm outside diameter, 40 cm				
	tubing, rubber or plastic, 60 cm				
	Y-tube or T-piece				
1	*Scissors	3,5			15
1	*Timepiece with second hand	7			15
75 cm	Tubing, rubber or plastic	3			15
4–6	*Weights, such as bricks or large books, equal in mass		11		15
10 cm	Wire, #22 copper or steel		11		15
1	*Resource Unit 1*	3			6
1	*Resource Unit 4*		11		6
1	*Resource Unit 5*		11		6
1	*Resource Unit 6*		11		6
1	*Resource Unit 12*	8		15	6
1	*Resource Unit 13*	7			6

*Items that can be obtained locally.

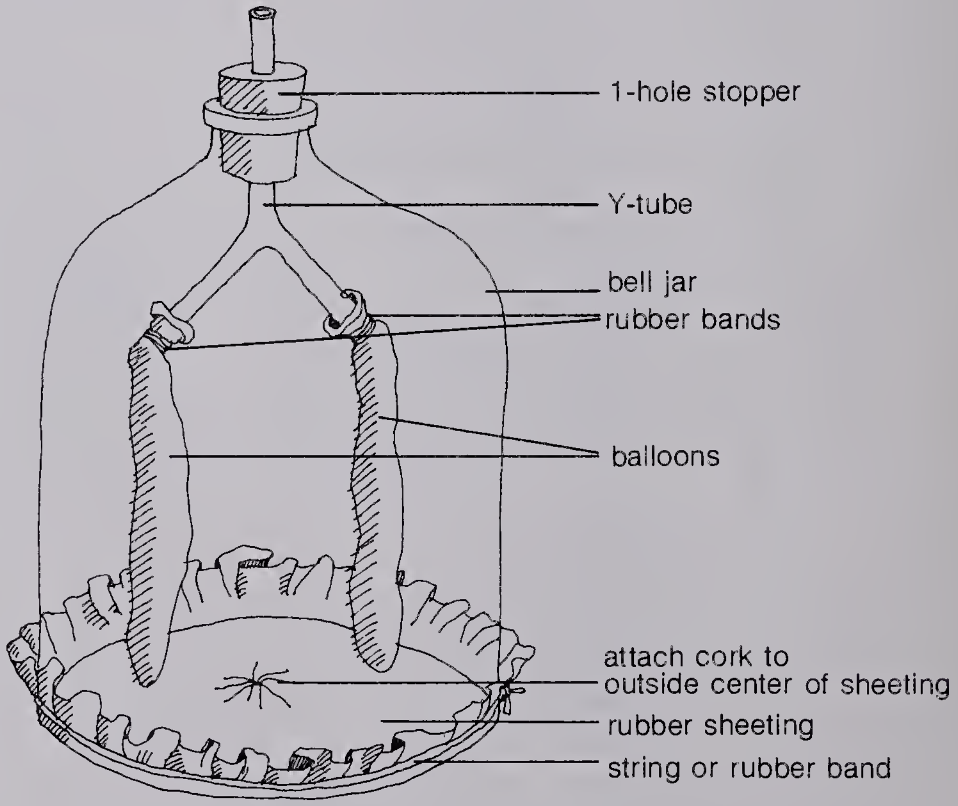
§If you prefer to construct your own pressure-volume apparatus, see Advance Preparation, p. TM 9. Equipment needs include an air piston, burette clamp, ring stand, wooden block, and drill.

Activity 3 Core Page 11

The diaphragm apparatus needed for this activity is a lung-model demonstration to give students firsthand experience with the idea of a pressurized breathing system. Refer to the illustration to assemble the apparatus from the materials listed. Before fitting the rubber sheeting, tie the small cork or a similar object into the center of the sheeting to act as a handle.

Label the setup *Getting Enough Oxygen, Activity 3.*

bell jar (or bottomless gallon jar of glass or clear plastic)
rubber or cork stopper, 1-hole, to fit
Y-tube
2 large balloons
rubber sheeting
2 small rubber bands, to attach balloons to Y-tube
small cork, to act as handle
string or large rubber band, to attach sheeting



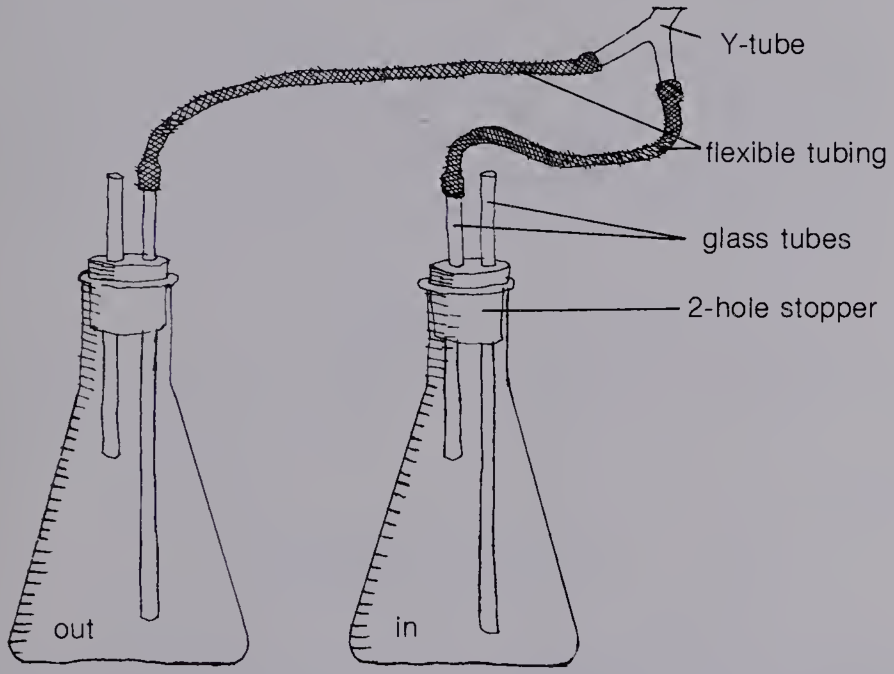
Activity 5 Core Page 21

Refer to the following illustration and directions to assemble the respiration apparatus from the materials listed.

Label the setup *Getting Enough Oxygen, Activity 5.*

2 Erlenmeyer flasks, 125-ml
2 rubber stoppers, 2-hole, #6
glass tubing, 40 cm
rubber or plastic tubing, 60 cm
Y-tube or T-piece
grease pencil, for labeling flasks

Cut the glass tubing into four lengths: two 8-cm lengths and two 12-cm lengths. Firepolish the ends of the tubes in a burner flame, then insert the tubes, one of each length, into the stoppers as shown. Insert the shorter tube first, and use soapy water or glycerine to lubricate the stopper holes.



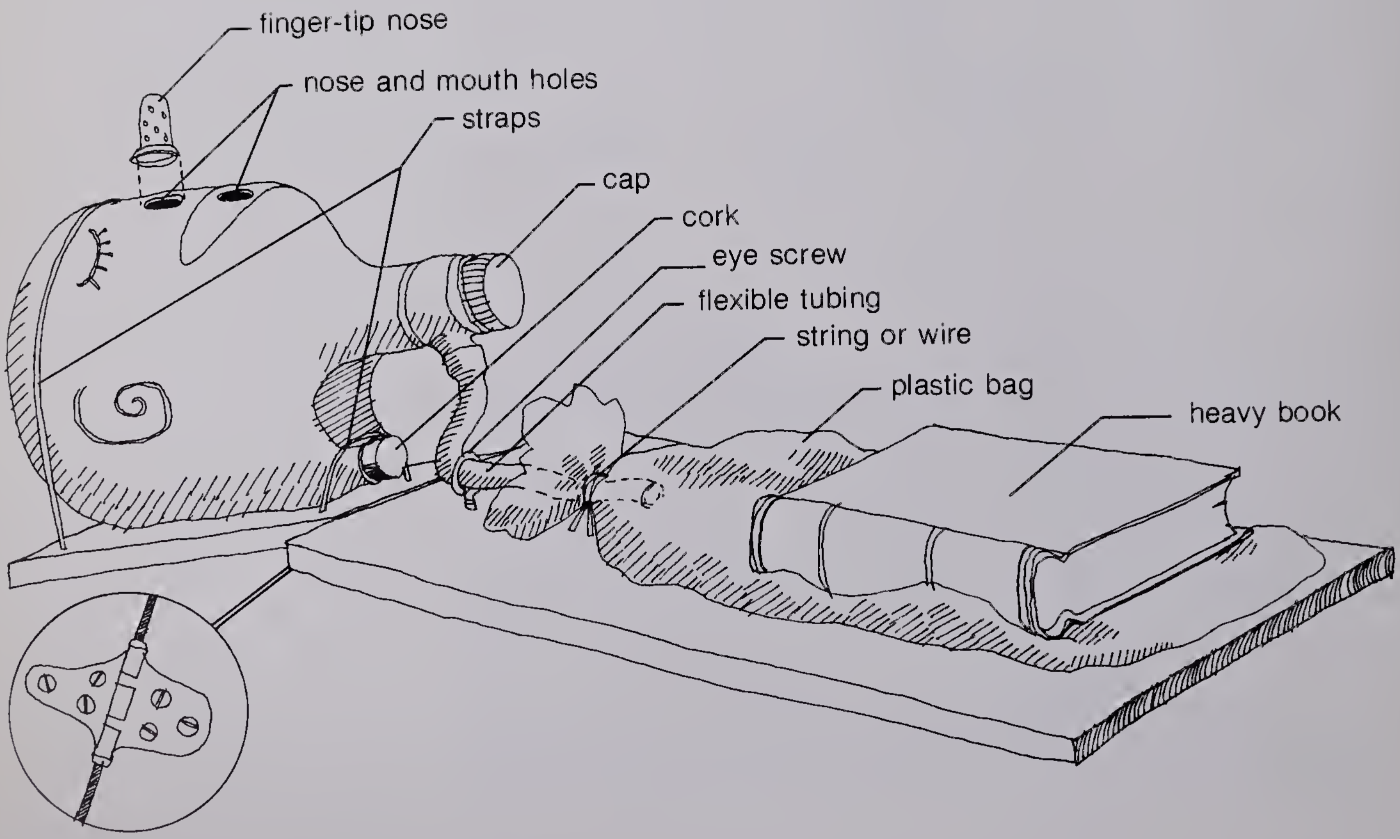
Cut two 30-cm lengths of the rubber or plastic tubing and fit these to the arms of the Y-tube. If you're using a T-piece, you may need slightly longer pieces of flexible tubing. Attach one piece of the flexible tubing to the shorter glass tube in one stopper. Label that flask *in.* Attach the other piece of flexible tubing to the longer glass tube in the other stopper. Label that flask *out.*

Preparation of limewater: Place 5 grams of calcium hydroxide into a litre container. Add 1 litre of tap water. Stopper the container and shake the contents vigorously, then let stand for 24 hours. The undissolved solid will settle to the bottom; the clear liquid above the solid is limewater. Pour off the liquid, through a filter if necessary, into a labeled supply bottle. Keep the bottle well stoppered.

Activity 6 Core Page 25

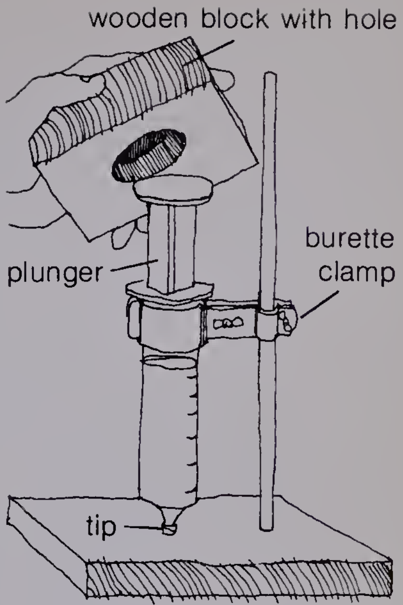
You may wish to construct, or have students construct, a homemade training device for practicing the mouth-to-mouth resuscitation technique. If so, refer to the following illustration and materials list to construct the model.

plastic gallon jug, clean with tight-fitting cap
knife, to cut handle off jug and to cut holes for mouth and nose
rubber or plastic tubing, 20 cm
rubber or cork stopper
2 wooden boards, one about same dimensions as jug, one about three times that size
hinge and screws to attach boards
screwdriver
straps, string or wire, to hold jug in place
rubber finger tip, to act as nose
glue, to fasten finger tip to jug
plastic bag, 1-litre or larger
string, to tie plastic bag tightly to tubing
heavy book
large screw eye, to hold tubing in place
grease pencil, to draw facial features



Activity 11 Advanced Page 50

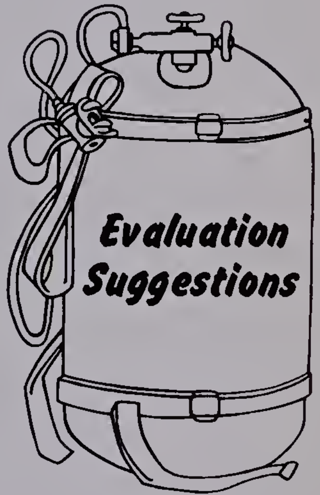
It is possible to construct a good working model of the pressure-volume apparatus yourself. Refer to the illustration and the directions that follow to assemble the apparatus from the materials listed. Label the apparatus *Getting Enough Oxygen, Activity 11*.



large air piston or 35-cc disposable medical syringe
burette clamp
ring stand
wooden block, about 15 cm x 8 cm
drill, with 1″ bit

Drill a hole part way through one surface of the wooden block. The hole should be large enough in diameter to fit over the top of the piston's plunger.

If the piston or syringe has a plastic tip, make sure it is securely attached. Clay or plasticene may help. If there is no tip, glue or melt the end to form an airtight seal. Students could put a length of wire between the piston and plunger during readjustment to provide the necessary air space for the readjustment.



In addition to the use of the Minicourse Test, you might want to use some or all of the following suggestions as part of your evaluation.

Essay Questions

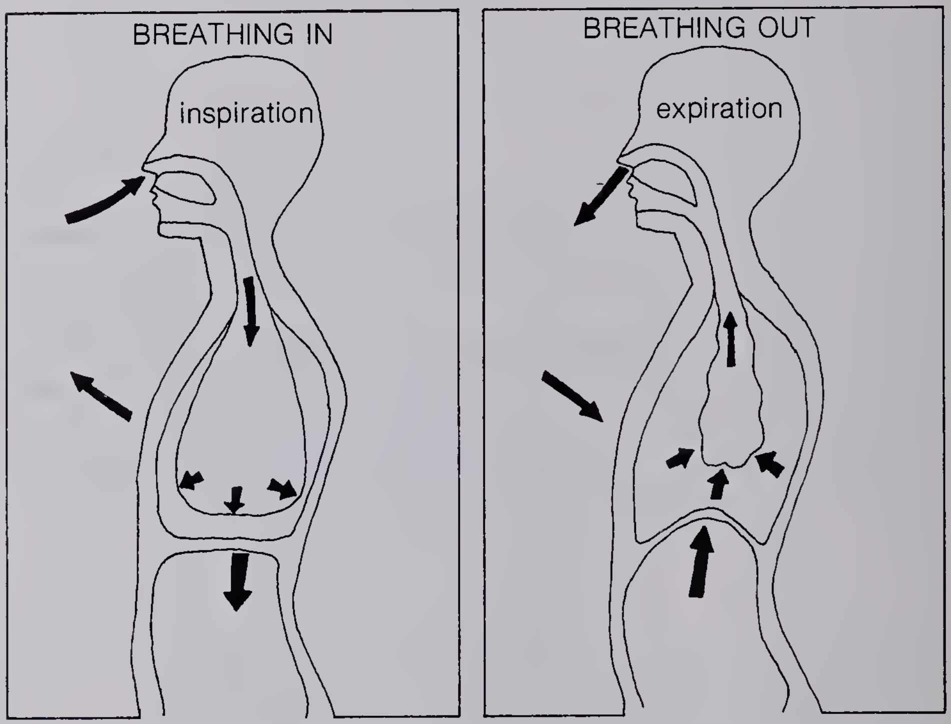
Four essay suggestions and their possible answers follow. All are related to core material, though some will be more suitable for the advanced student.

1. Describe how breathing rate is controlled in terms of a feedback system. Include a diagram to show how this feedback system works. You may wish to refer to *Resource Unit 13* for help.

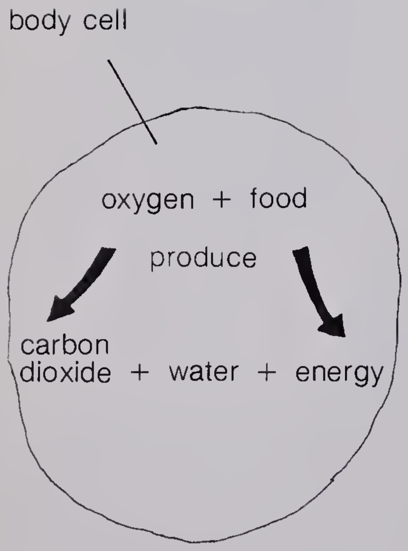
Answer: Feedback systems are steadying systems. When one thing changes, something else happens to bring things back to where they were. The student's answer and diagram should show the following order of events: CO_2 in blood increases; control center senses the increase; control center causes breathing rate to increase; CO_2 in blood decreases; control center senses the decrease; control center causes breathing rate to decrease.

2. Describe the differences between breathing and respiration. Include a labeled diagram of each.

Answer: Breathing is the process of taking air in and out of the body. The incoming air is cleaned, warmed, and moistened before being used. A labeled diagram of the process of breathing is shown below.



Respiration is the process of combining oxygen and food inside the cells to provide the energy that cells need to maintain themselves and to do their various jobs. Refer to the diagram to the left for what happens during respiration.



3. Compare and contrast the causes, symptoms, and treatments of colds and chronic bronchitis.

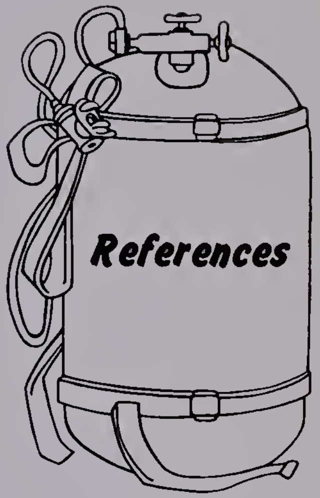
Answer: Colds are caused by many different viruses, whereas chronic bronchitis is caused by the continuous irritation of the linings of the bronchial tubes. Some of the symptoms of colds are scratchy throat, runny or stopped-up nose, coughing, chills, and sneezing. Symptoms of chronic bronchitis are a constant, loose and rattling cough followed by spitting up of large amounts of sputum. There is no cure for the common cold; only the symptoms can be treated. Aspirin, liquids, and rest can help. Chronic bronchitis can be treated by avoiding smoking and other sources of bronchial irritation. Medication can help to open the bronchial tubes.

4. Describe the four main steps in mouth-to-mouth resuscitation.

Answer:

Step 1. Clear victim's mouth and air passage.
Step 2. Tilt victim's head backwards; use thumb and index

Step 3. Place your mouth over victim's mouth and blow. Stop blowing when victim's chest has expanded.
Step 4. Repeat every 3 to 5 seconds until medical help arrives or victim starts to breathe normally.



American Lung Association. 1973. *Introduction to lung diseases.* 5th ed. New York.
This book presents pertinent facts about the principal respiratory diseases. While written for the layperson, the language is medical in tone and therefore more suited for the teacher and for advanced students.

American Lung Association. 1975. *. . . the facts.* New York.
A series of short pamphlets on various respiratory diseases. These pamphlets would be useful when playing the game *Diagnosis.*

American Medical Association. 1974. Standards for cardio-pulmonary resuscitation (CPR) and emergency cardiac care (ECC). *Journal of the American Medical Association* 227, no. 7.
Available from the American Heart Association (44 East 23rd Street, New York, N.Y. 10010), this publication is a basic training resource.

American National Red Cross. 1973. *Advanced first aid and emergency care.* New York: Doubleday and Co.
Chapters 5 and 6 may be used as a more complete reference on what to do in case of breathing emergencies.

Brecher, Ruth, and Brecher, Edward. 1968. *Breathing . . . what you need to know.* New York: American Lung Association.
A well-written booklet on breathing, this title contains useful information on respiratory diseases and smoking. It is appropriate for use by all students.

BSCS. 1973. *Biological science: an inquiry into life.* 3rd ed. New York: Harcourt Brace Jovanovich, Inc.
Chapter 12 contains useful information about hemoglobin. A

detailed discussion of the nervous control of breathing is found on pages 262–265. Suitable as a reference for the teacher and for advanced students.

BSCS. 1973. *Molecules to man.* 3rd ed. Boston: Houghton Mifflin Company.

Chapter 10 presents basic information on cellular respiration and would be useful with Advanced Activity 10. Chapter 21 provides more advanced information on some of the topics treated in the minicourse core.

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Acknowledgments

In addition to the major effort by the ISIS permanent staff, writing conference participants, and author-consultants (listed on the inside back cover), the following contributed to this minicourse.

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FOREWORD

Evidence has been mounting that something is missing from secondary science teaching. More and more, students are rejecting science courses and turning to subjects that they consider to be more practical or significant. Numerous high school science teachers have concluded that what they are now teaching is appropriate for only a limited number of their students.

As their concern has mounted, many science teachers have tried to find instructional materials that encompass more appropriate content and that allow them to work individually with students who have different needs and talents. For the most part, this search has been frustrating because presently such materials are difficult, if not impossible, to find.

The Individualized Science Instructional System (ISIS) project was organized to produce an alternative for those teachers who are dissatisfied with current secondary science textbooks. Consequently, the content of the ISIS materials is unconventional as is the individualized teaching method that is built into them. In contrast with many current science texts which aim to ''cover science,'' ISIS has tried to be selective and to limit our coverage to the topics that we judge will be most useful to today's students.

Obviously the needs and problems of individual schools and students vary widely. To accommodate the differences, ISIS decided against producing tightly structured, pre-sequenced textbooks. Instead, we are generating short, self-contained modules that cover a wide range of topics. The modules can be clustered into many types of courses, and we hope that teachers and administrators will utilize this flexibility to tailor-make curricula that are responsive to local needs and conditions.

ISIS is a cooperative effort involving many individuals and agencies. More than 75 scientists and educators have helped to generate the materials, and hundreds of teachers and thousands of students have been involved in the project's nationwide testing program. All of the ISIS endeavors have been supported by generous grants from the National Science Foundation. We hope that ISIS users will conclude that these large investments of time, money, and effort have been worthwhile.

Ernest Burkman
ISIS Project
Tallahassee, Florida

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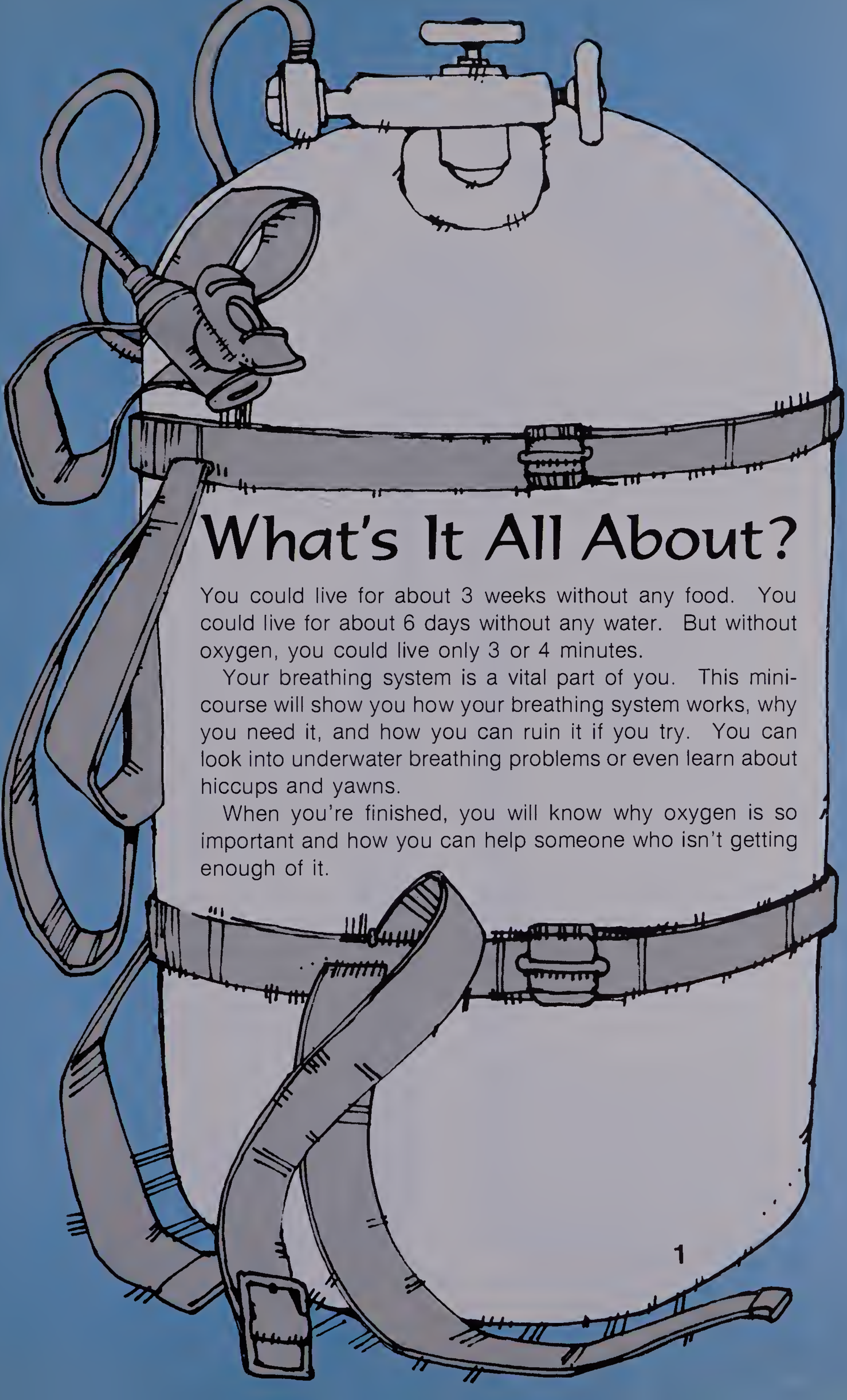


What's It All About?

You could live for about 3 weeks without any food. You could live for about 6 days without any water. But without oxygen, you could live only 3 or 4 minutes.

Your breathing system is a vital part of you. This mini-course will show you how your breathing system works, why you need it, and how you can ruin it if you try. You can look into underwater breathing problems or even learn about hiccups and yawns.

When you're finished, you will know why oxygen is so important and how you can help someone who isn't getting enough of it.

Core

Activity 1 Planning

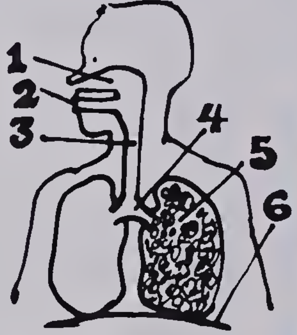
If you have trouble with any of the first three objectives, do Activity 2 first. Any other activities you need to do can be done in any order.

Activity 2 Page 5

Objective 1: Identify these parts of the human breathing system: diaphragm, alveoli, bronchioles, bronchi, trachea, epiglottis, pharynx, nasal cavity, nostrils.

Sample Question: Match the letter of each part with the number of the arrow that points to it.

a. diaphragm
b. nasal cavity
c. alveolus
d. trachea



Objective 2: Trace the path of air from the nostrils to the alveoli.

Sample Question: After an inhaled breath of air passes through the nasal cavity, in what order does it pass through these parts?

a. trachea
b. bronchial tubes
c. pharynx
d. alveoli

Objective 3: Describe how air is cleaned and warmed in the breathing system.

Sample Question: What helps clean the air you breathe?

a. alveolus
b. blood vessel
c. mucus
d. larynx

Activity 3 Page 11

Objective 4: Explain how movements of the chest and diaphragm cause air to enter and leave the lungs.

Sample Question: What happens when the diaphragm moves up?

a. Pressure on the lungs decreases.
b. Pressure on the stomach increases.
c. The heart beats faster.
d. Air leaves the lungs.

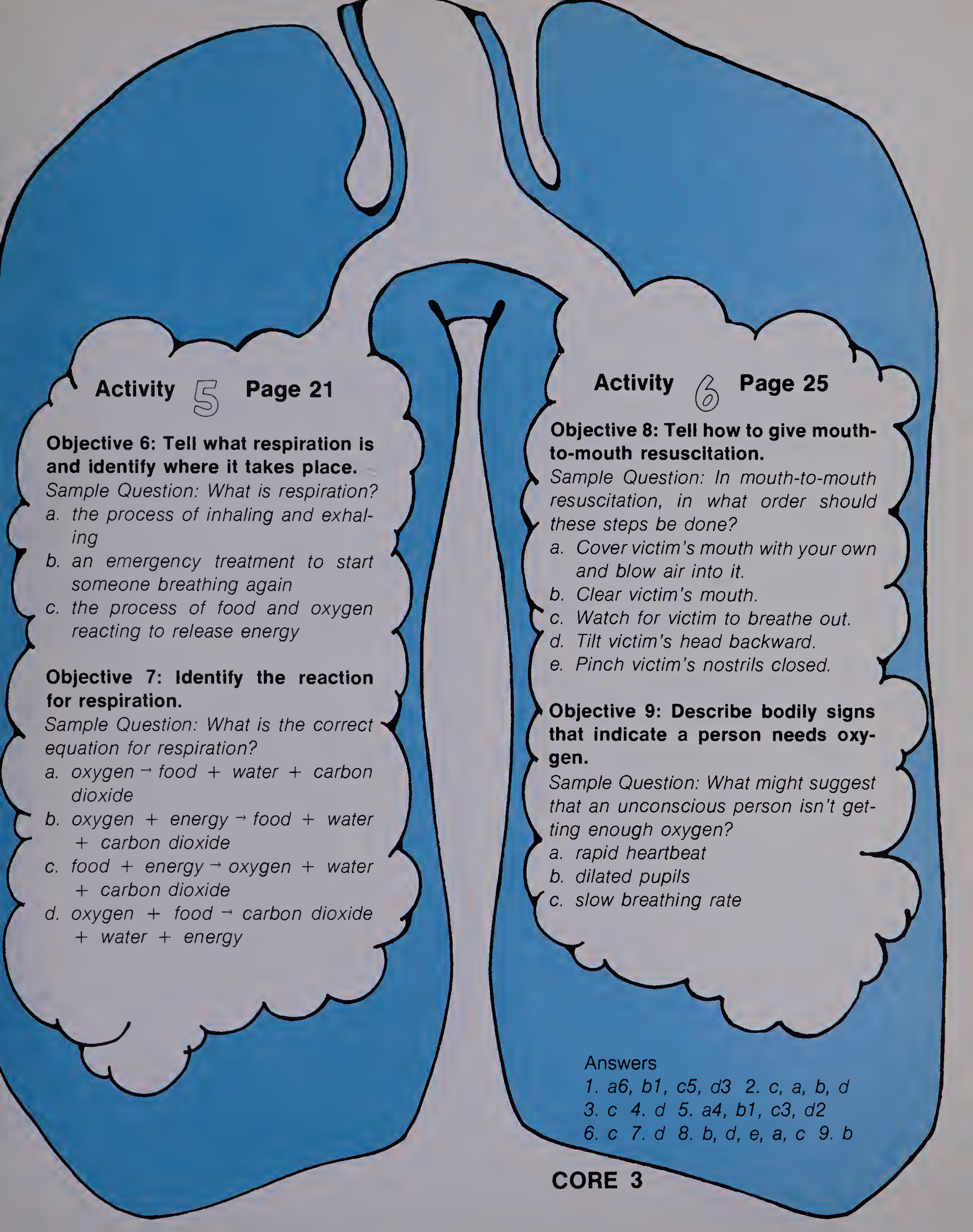
Activity 4 Page 19

Objective 5: Describe the causes, effects, symptoms, and treatments for the common cold, influenza, pneumonia, emphysema, asthma, chronic bronchitis, and carbon monoxide poisoning.

Sample Question: Match each respiratory condition in List A with its cause in List B.

List A
a. asthma
b. common cold
c. emphysema
d. pneumonia

List B
1. virus
2. bacteria or virus
3. smoking or air pollution
4. food, pollen, or dust
5. fungus



Activity 5 Page 21

Objective 6: Tell what respiration is and identify where it takes place.

Sample Question: What is respiration?

a. the process of inhaling and exhaling
b. an emergency treatment to start someone breathing again
c. the process of food and oxygen reacting to release energy

Objective 7: Identify the reaction for respiration.

Sample Question: What is the correct equation for respiration?

a. oxygen → food + water + carbon dioxide
b. oxygen + energy → food + water + carbon dioxide
c. food + energy → oxygen + water + carbon dioxide
d. oxygen + food → carbon dioxide + water + energy

Activity 6 Page 25

Objective 8: Tell how to give mouth-to-mouth resuscitation.

Sample Question: In mouth-to-mouth resuscitation, in what order should these steps be done?

a. Cover victim's mouth with your own and blow air into it.
b. Clear victim's mouth.
c. Watch for victim to breathe out.
d. Tilt victim's head backward.
e. Pinch victim's nostrils closed.

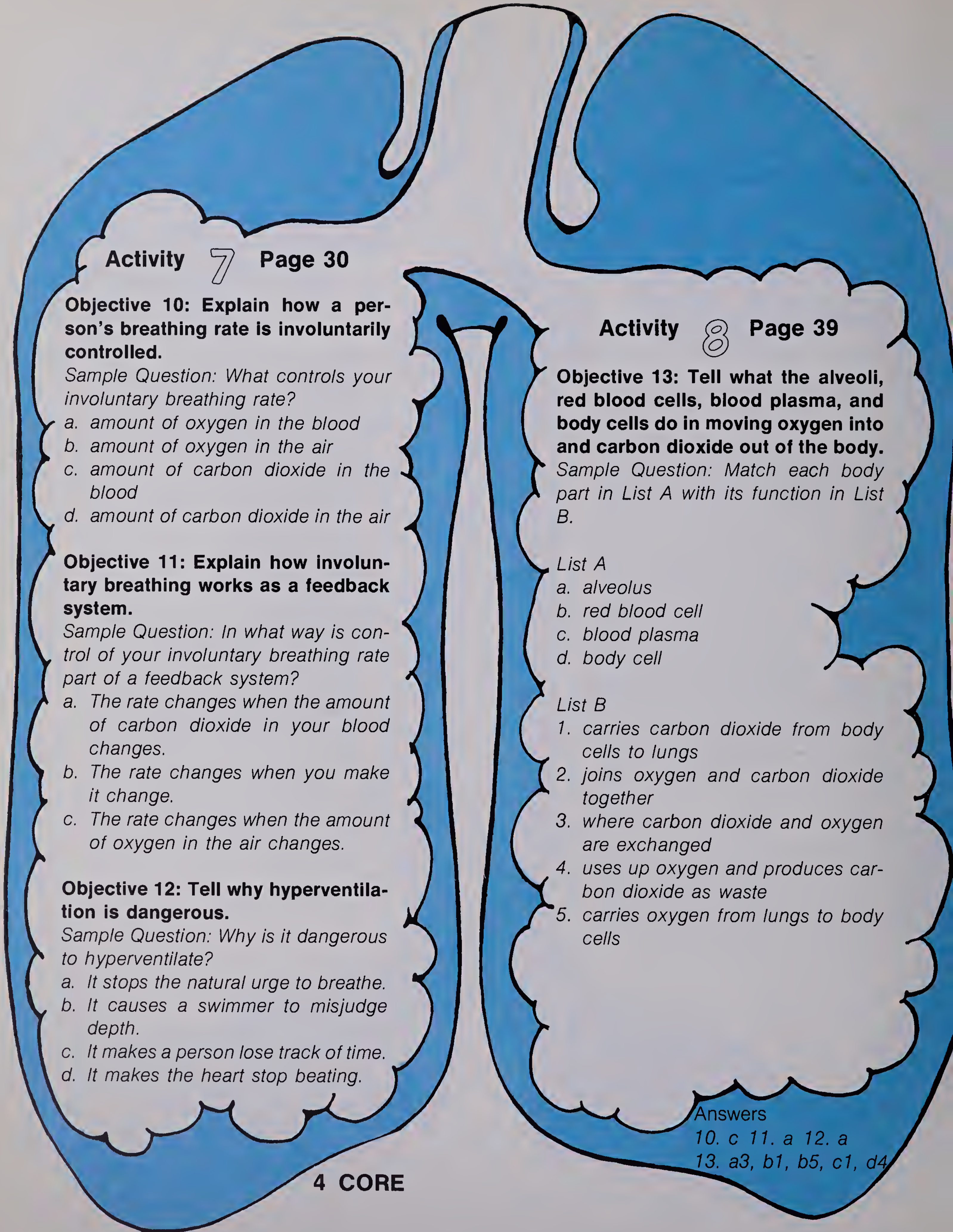
Objective 9: Describe bodily signs that indicate a person needs oxygen.

Sample Question: What might suggest that an unconscious person isn't getting enough oxygen?

a. rapid heartbeat
b. dilated pupils
c. slow breathing rate

Answers
1. a6, b1, c5, d3 2. c, a, b, d
3. c 4. d 5. a4, b1, c3, d2
6. c 7. d 8. b, d, e, a, c 9. b

CORE 3



Activity 7 Page 30

Objective 10: Explain how a person's breathing rate is involuntarily controlled.

Sample Question: What controls your involuntary breathing rate?

a. amount of oxygen in the blood
b. amount of oxygen in the air
c. amount of carbon dioxide in the blood
d. amount of carbon dioxide in the air

Objective 11: Explain how involuntary breathing works as a feedback system.

Sample Question: In what way is control of your involuntary breathing rate part of a feedback system?

a. The rate changes when the amount of carbon dioxide in your blood changes.
b. The rate changes when you make it change.
c. The rate changes when the amount of oxygen in the air changes.

Objective 12: Tell why hyperventilation is dangerous.

Sample Question: Why is it dangerous to hyperventilate?

a. It stops the natural urge to breathe.
b. It causes a swimmer to misjudge depth.
c. It makes a person lose track of time.
d. It makes the heart stop beating.

Activity 8 Page 39

Objective 13: Tell what the alveoli, red blood cells, blood plasma, and body cells do in moving oxygen into and carbon dioxide out of the body.

Sample Question: Match each body part in List A with its function in List B.

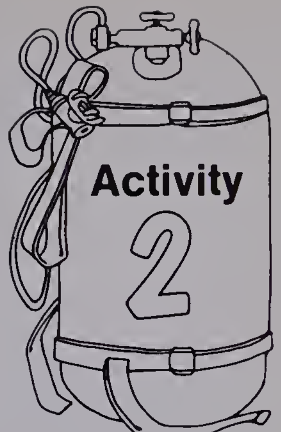
List A
a. alveolus
b. red blood cell
c. blood plasma
d. body cell

List B
1. carries carbon dioxide from body cells to lungs
2. joins oxygen and carbon dioxide together
3. where carbon dioxide and oxygen are exchanged
4. uses up oxygen and produces carbon dioxide as waste
5. carries oxygen from lungs to body cells

Answers
10. c 11. a 12. a
13. a3, b1, b5, c1, d4

Your Breathing System

ACTIVITY EMPHASIS: The parts of the human respiratory system and their functions; how the system acts as an efficient air conditioner.



MATERIALS PER STUDENT UNIT
small mirror
penlight (or flashlight)
tongue depressor

Breathe in, breathe out. Inhale, exhale. No medical checkup is complete without these words.

Follow a breath of air as it flows into your respiratory, or breathing, system. You'll need these items:

small mirror
penlight
tongue depressor

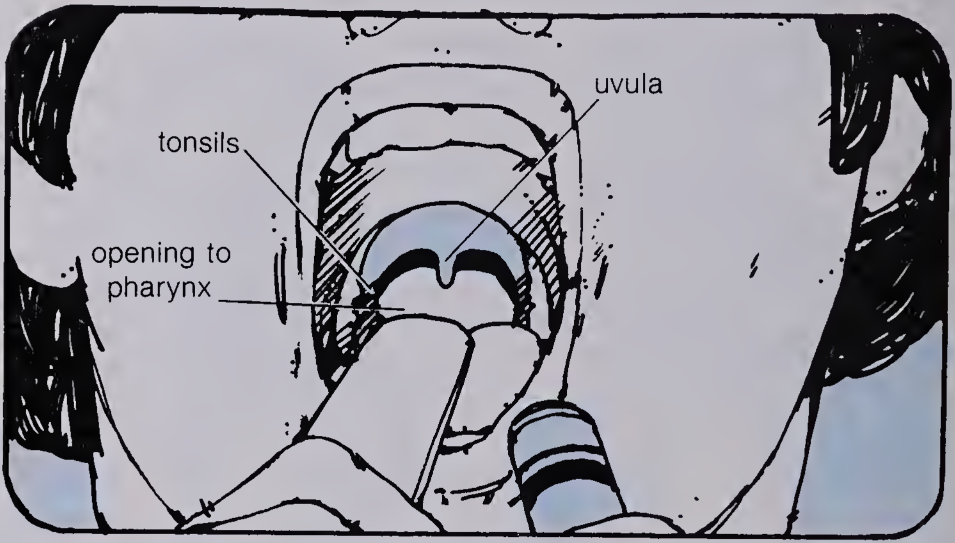
A. One way air gets into the body is through the nostrils. Use the mirror and penlight to look into your nostrils.

✓ 2–1. Describe what you see.

2-1. Hairs, and perhaps dirt, in a sticky substance.

The inside of your nose is called the *nasal cavity.* You were probably able to see some hairs and the beginning of the moist inner passages. Once the air has passed through the nasal passages, it enters the throat, or *pharynx* [FAIR-inks].

B. Prop the mirror up in front of you. Use the tongue depressor and penlight to look inside your mouth. Besides your teeth and tongue, you should be able to see your tonsils (if you still have them), your uvula, and the opening to your pharynx.



Of course, air can enter through the mouth or the nose to get to the pharynx. But try to take air in through your mouth and nose at the same time. If you can do it, you have to make yourself do it. Normally, you breathe through either one or the other. And it's better to breathe through your nose, as you'll find out later on.

Students may note that air sometimes does get into the stomach, causing a person to belch. And babies are burped to release air taken in with their milk.

Say you do breathe through your mouth. Air isn't the only thing that gets into your body that way. So does food. You'd be in trouble if food got into your lungs, and you'd be pretty uncomfortable if air ended up in your stomach. Fortunately, the body is built to direct air and food to the right places. Just try breathing through your nose and swallowing at the same time.

A flap of tissue called the *epiglottis* [ep-i-GLOT-us] keeps you from breathing and swallowing at the same time. Look at Figure 2–1. When you swallow, the epiglottis flops down over the *trachea* [TRAY-kee-ah]. The food is directed down the tube that leads to the stomach. But when you breathe, the epiglottis is up and the air passes by it. The air goes through the voice box, or larynx, and into the trachea. You may have heard the trachea called your "windpipe."

Epiglottis does not actually close trachea off completely, but enough so to direct food away from tracheal opening and into esophagus.

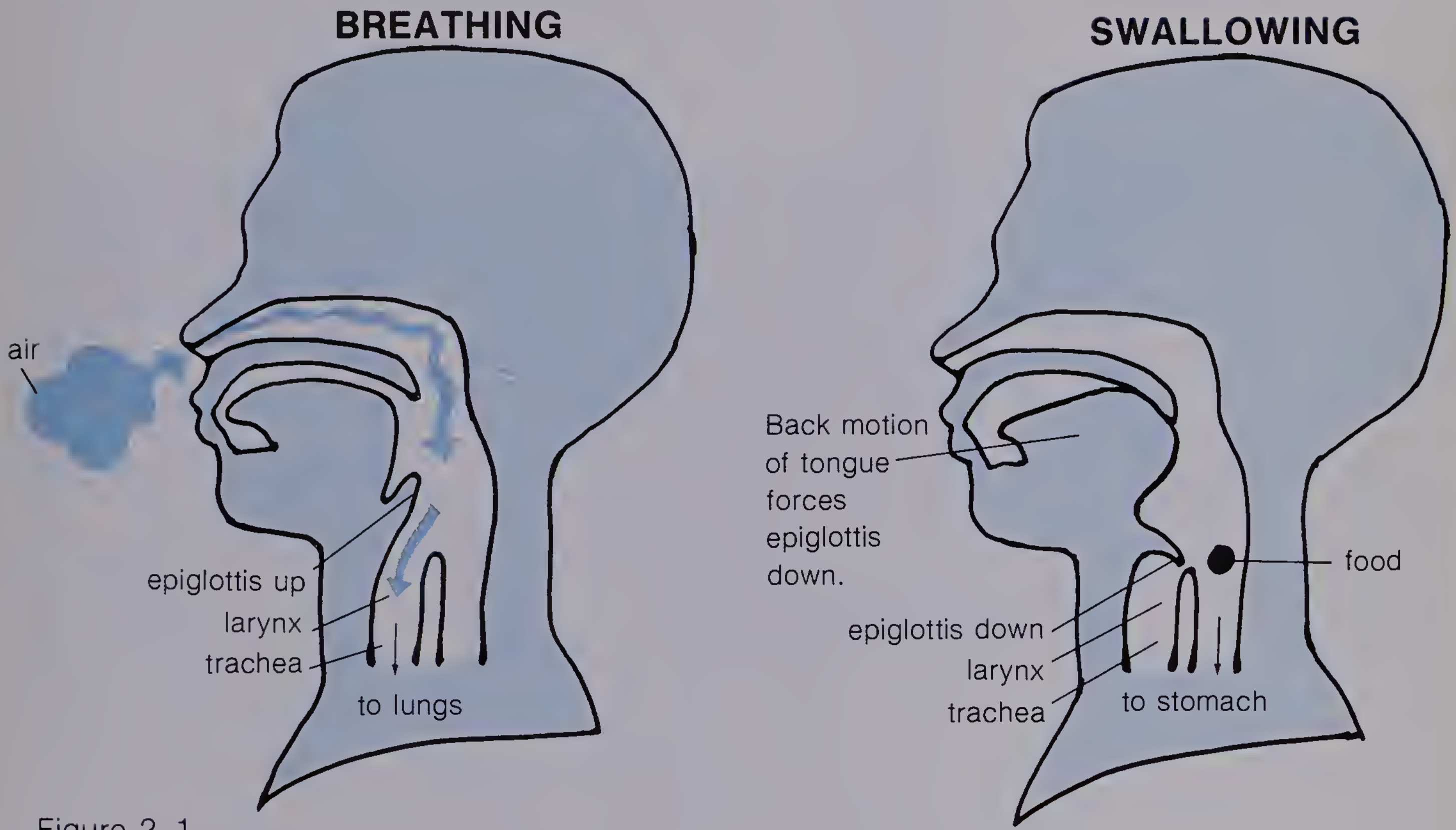


Figure 2–1

✓ 2–2. Sometimes a bit of food does get into the trachea. What do you do when that happens? 2-2. Choke and cough.

The trachea branches into two tubes. Each of the tubes is called a *bronchus* [BRON-kus], and together they are the *bronchi* (see Figure 2–2).

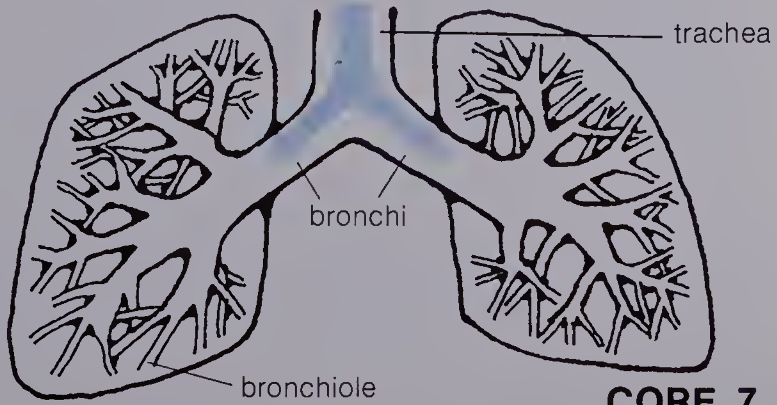
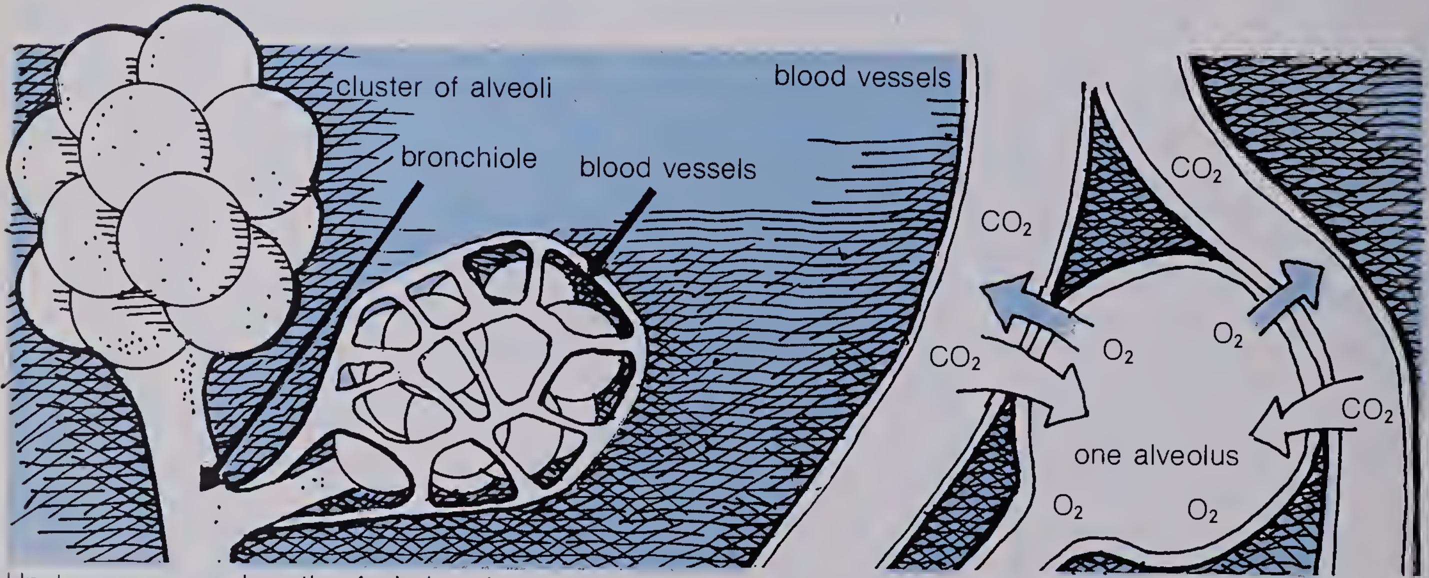


Figure 2–2

All the tubes from bronchi to bronchioles are described generally as bronchial tubes. The diminutive *-ole* ending merely defines bronchioles as very tiny bronchial tubes.

So, having passed through the trachea, the air splits toward each lung. After entering the lungs, the bronchi split again and again into smaller and smaller air tubes, finally becoming *bronchioles.*

Each bronchiole ends with several tiny, raspberry-shaped air sacs called *alveoli* [al-VEE-a-lye], shown in Figure 2–3. Each alveolus is only one-quarter of a millimetre across, but there are millions of them forming your lungs. If you were to spread all your alveoli out, you'd have about 60 square metres of surface area. This means that a large surface is exposed to the breath of air you've taken in. And oxygen can pass into your body anywhere along that surface.



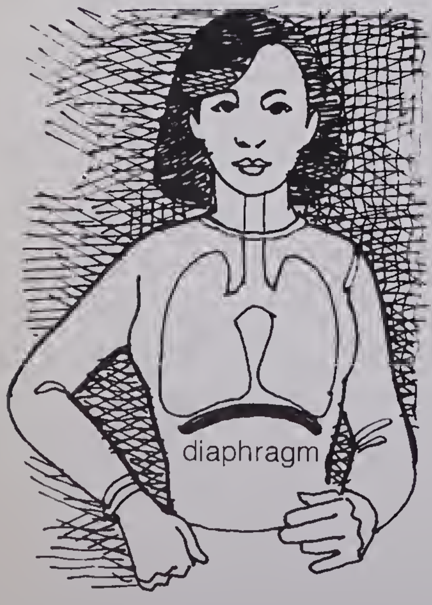
Up to now, your breath of air has been in a tube still open on one end to the outside world.

In the alveoli, oxygen in the air passes through the alveolar membrane. Part of the air is finally taken into the body.

Figure 2–3

The tissue that holds the alveoli together is loaded with tiny blood vessels. Oxygen (O_2) passes through the alveoli and into the bloodstream. And carbon dioxide (CO_2), a gaseous waste, passes out of the bloodstream into the alveoli.

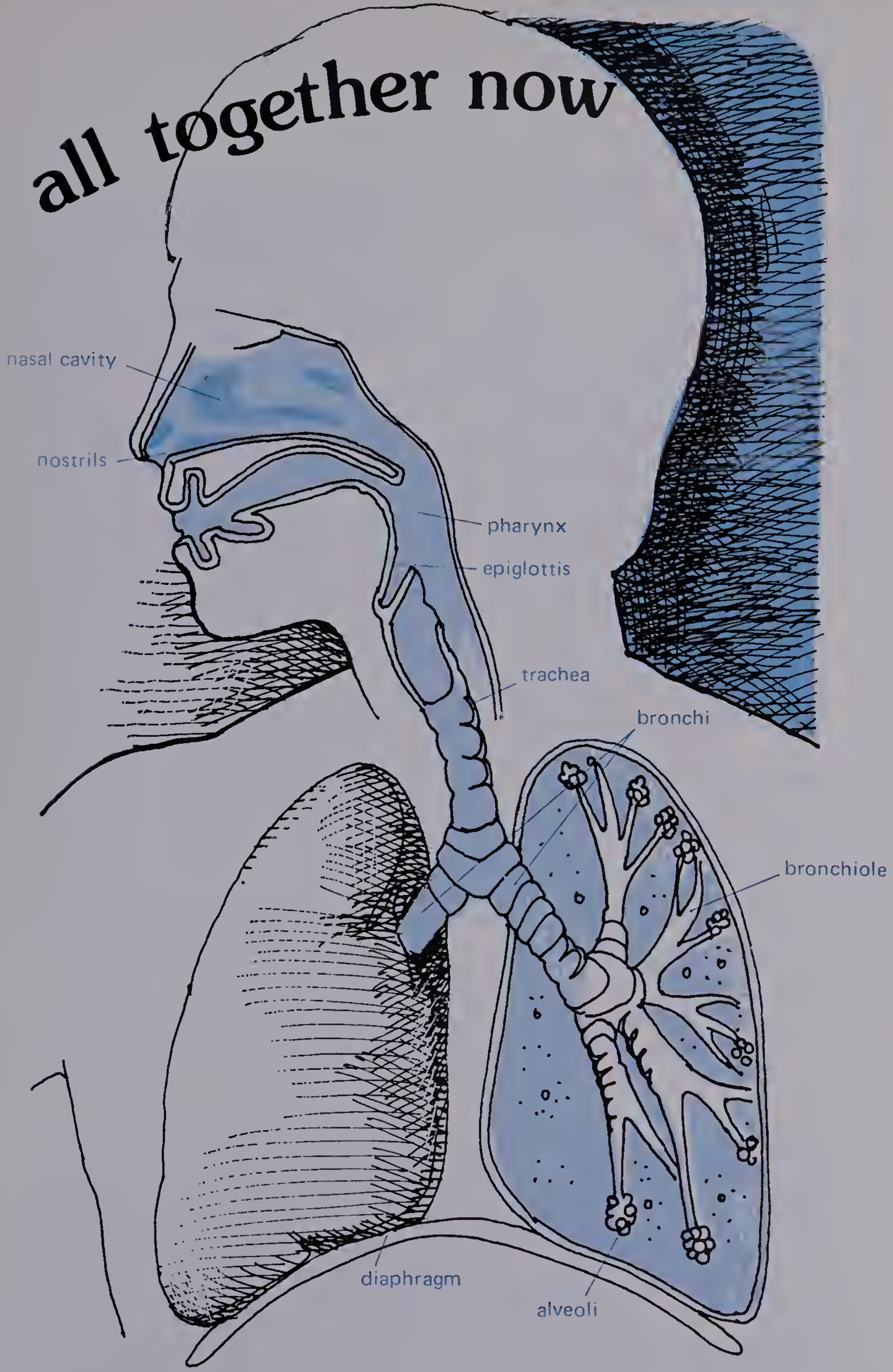
Activity 8 goes into more detail on this gaseous exchange.



★ **2–3. When you exhale, you breathe out unused air plus carbon dioxide. Name the parts of your breathing system in the order that an exhaled breath passes through them. Begin with the alveoli.** 2-3. Alveoli, bronchioles, bronchi, trachea, pharynx, nasal cavity, and nostrils, or pharynx to mouth.

There is one more part to your breathing system — the *diaphragm* [DYE-ah-fram]. The muscular, dome-shaped diaphragm lies below the lungs. Movements of the diaphragm make it possible for you to breathe. The diaphragm pushes air out of the lungs and pulls air into the lungs. In Activity 3, students get a chance to see a "diaphragm" in action and learn more about the pressurized breathing system.

all together now



★ **2–4. Draw a sketch of your breathing system. Label the diaphragm, alveoli, bronchioles, bronchi, trachea, epiglottis, pharynx, nasal cavity, and nostrils.**

2-4. [See labels on drawing.]

Your breathing system does more for you than just move air in and out — it also acts as an efficient air-conditioning system. It warms air that is colder than your body temperature, and it cools air that is too warm. It cleans dirty air and moistens dry air.

Think of the maze of passages a breath of air goes through as it heads toward the alveoli. Your nostrils are just the beginning. Within your nasal cavity is a complicated set of air passages, some narrow and some wide. Farther down, in your lungs, the bronchial tubes branch again and again. Because of all this twisting and turning, a breath of hot or cold air is cooled or warmed to body temperature by the time it reaches the alveoli.

2-5. The air might not get to body temperature before reaching the lungs; it has a shorter trip through the mouth than through the nose.

✓ 2–5. Why do you suppose it's not a good idea to breathe very cold or very hot air through the mouth instead of through the nose?

From the nasal cavity to the bronchial tubes, the air passages are lined with a layer of cells called the *epithelium* [ep-i-THEE-lee-um]. There are two main kinds of epithelial cells. One kind gives off a moist, sticky material called *mucus*. The other kind has tiny, waving hairs called *cilia*. (See Figure 2–4.)

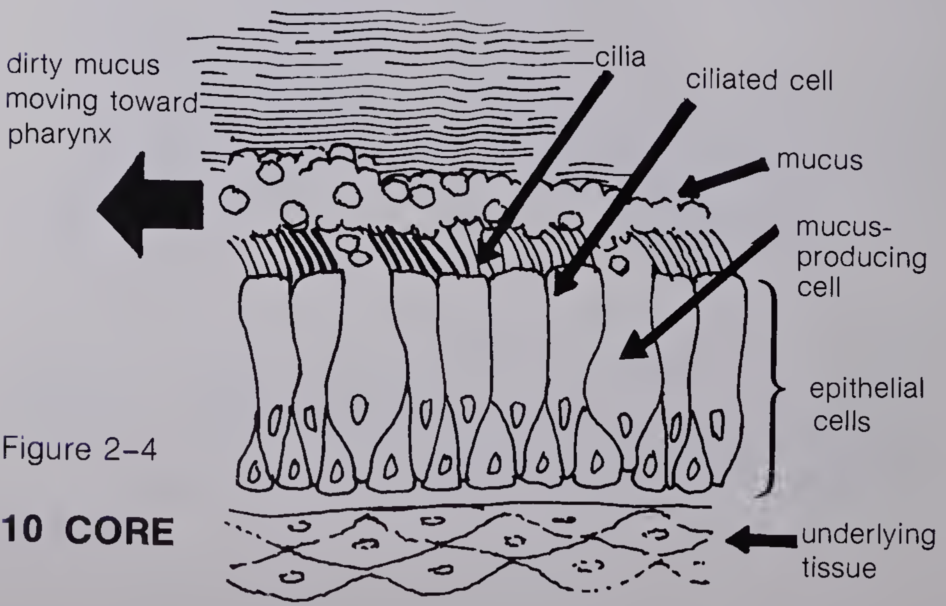
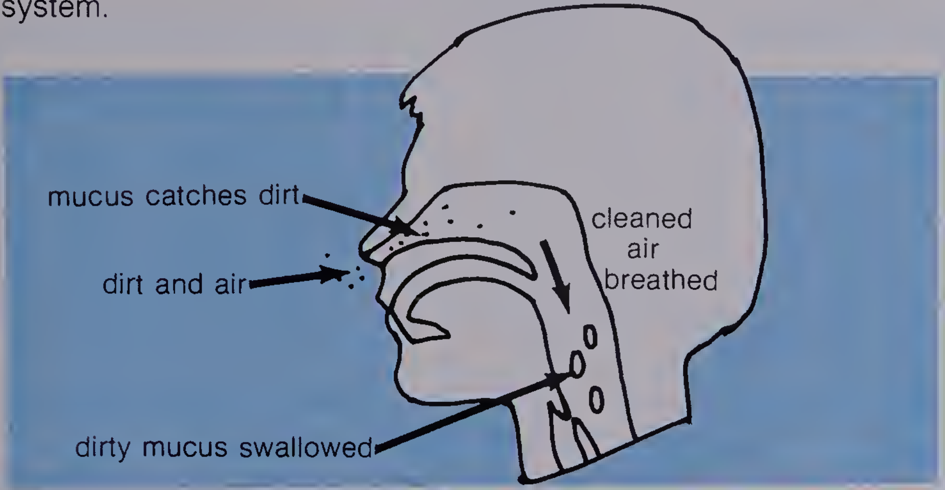


Figure 2–4

The mucus traps dirt and other foreign particles taken in with a breath of air. The waving cilia slowly move the dirty mucus toward the pharynx. There the mucus can be coughed or sneezed out, or it can be swallowed. Harmless in the digestive system, the foreign particles could have hurt the respiratory system.

Unhealthy respiratory conditions are taken up in Activity 4 and the value of mucus is again mentioned.



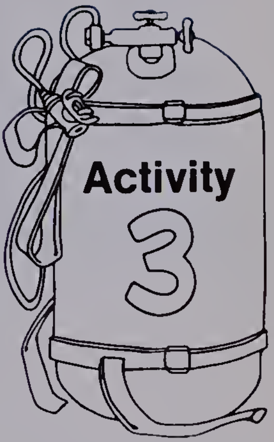
The mucus serves another function too. Since it is moist, it moistens dry air before the air enters your lungs. This prevents the alveoli from drying out.

2-6. It provides moisture, preventing alveoli from drying out; it traps dirt, keeping breathing passages clean.

★ 2–6. In what two ways is the production of mucus important to your breathing system?

ACTIVITY EMPHASIS: Diaphragm and rib muscles cause pressure variations in chest cavity and thus move air in and out of the lungs. Students estimate volume of air involved in one breath.

Moving the Air



You've been breathing ever since you were born. Day after day, night after night, the air flows in and the air flows out. This activity will show you how it's done.

MATERIALS PER STUDENT UNIT
- graduated cylinder or beaker, 100-ml
- jug, translucent plastic, 4-litre (1-gallon)
- grease pencil
- cellophane tape
- bucket, 8 litres or larger
- soda straw
- scissors (to cut straw)
- tubing, rubber or plastic, 75 cm
- *Resource Unit 1*
- assembled diaphragm apparatus (see Advance Preparation, p. TM 6)

Begin by finding out how much air you breathe and how much you *can* breathe. You'll need the following:

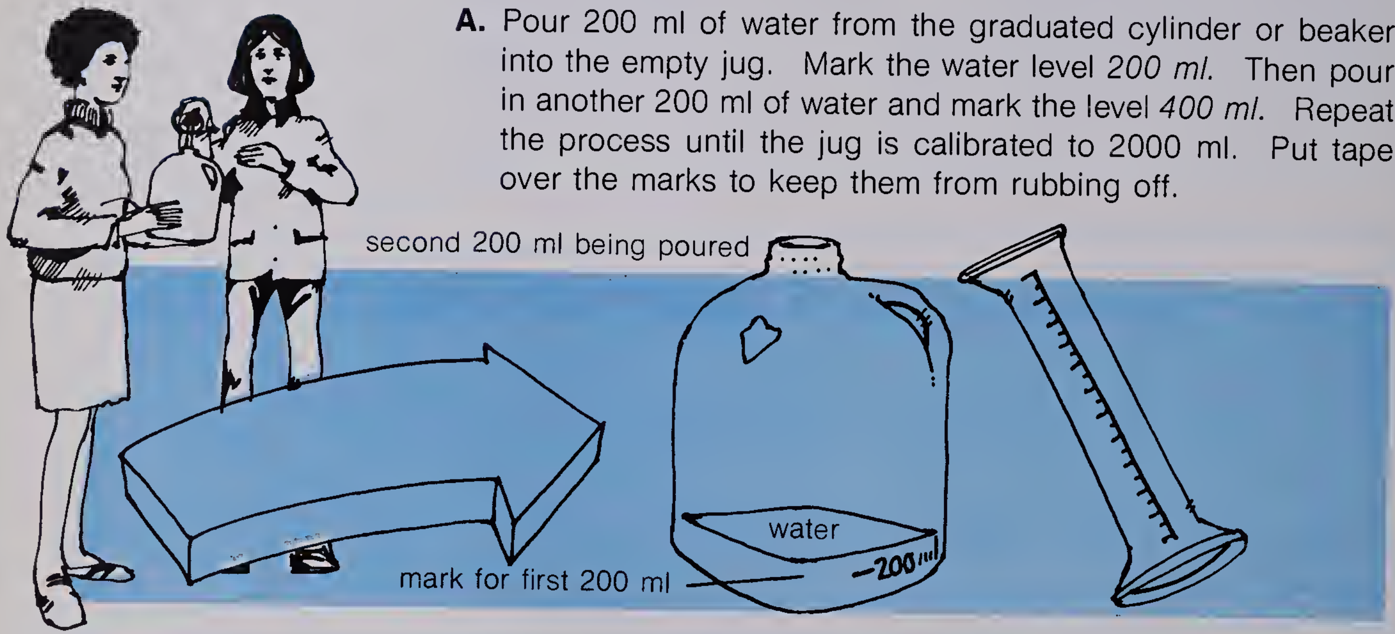
- a partner
- graduated cylinder or beaker, 100-ml
- plastic jug, 4-litre (1-gallon)
- grease pencil
- cellophane tape
- bucket, 8 litres or larger
- soda straw, 5 cm
- rubber or plastic tubing, 75 cm

If it will fit into the mouth of the jug, a piece of garden hose will offer less resistance to air being blown through it. Resistance is fairly high with the tubing listed.

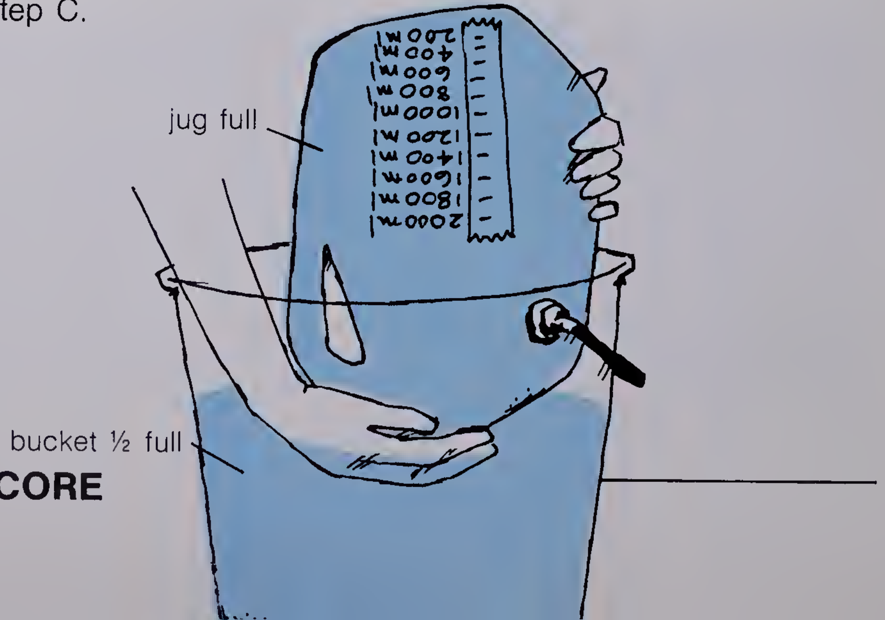
Due to all the water required, this activity can get messy. It should be carried out in a location where spilt water will not cause a problem.

You will begin by marking the jug so that you can measure with it. This is called *calibrating*.

A. Pour 200 ml of water from the graduated cylinder or beaker into the empty jug. Mark the water level *200 ml*. Then pour in another 200 ml of water and mark the level *400 ml*. Repeat the process until the jug is calibrated to 2000 ml. Put tape over the marks to keep them from rubbing off.

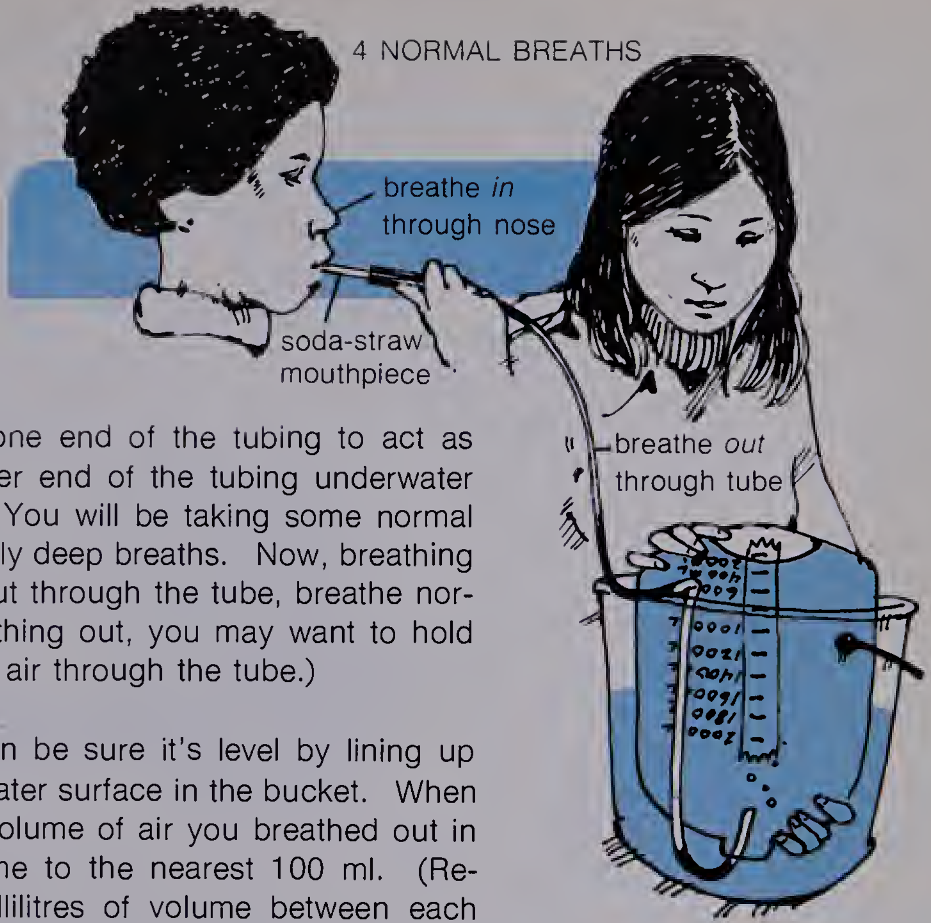


B. Fill the jug the rest of the way with water. Then half fill a bucket with water. Have your partner cover the jug with the palm of his or her hand and turn the jug upside down into the bucket. Have your partner hold the jug while you do Step C.



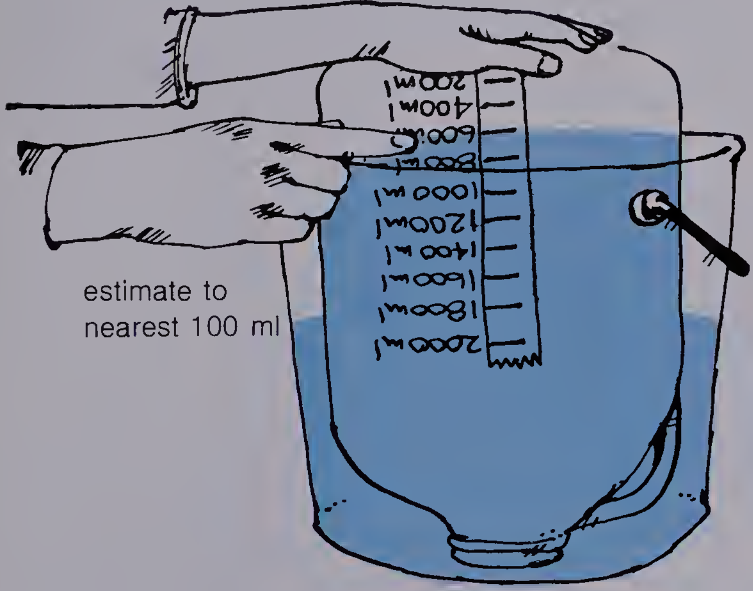
CAUTION

Be sure in Step C that you don't suck back on the straw after you've breathed into it.



C. Insert the soda straw into one end of the tubing to act as a mouthpiece. Put the other end of the tubing underwater into the mouth of the jug. You will be taking some normal breaths. Don't take unusually deep breaths. Now, breathing in through your nose and out through the tube, breathe normally 4 times. (When breathing out, you may want to hold your nose to help direct the air through the tube.)

D. Hold the jug level. You can be sure it's level by lining up the top of the jug with the water surface in the bucket. When they are parallel, read the volume of air you breathed out in 4 breaths. Read the volume to the nearest 100 ml. (Remember, there are 200 millilitres of volume between each mark.)



Have *Resource Unit 1* available to aid students in averaging.

✓ 3–1. What volume of air did you breathe out in 4 normal breaths? 3-1. A typical value might be 1000 to 1500 ml of air.

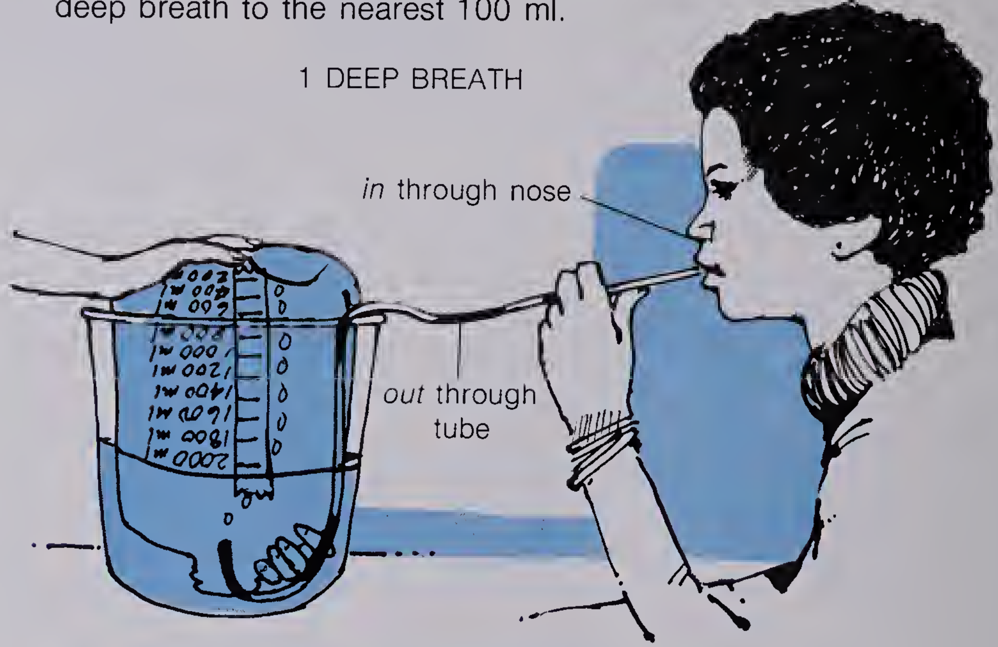
✓ 3–2. What was the average volume of each breath? (If you need help in finding the average, do *Resource Unit 1*.)

3-2. $\frac{1000\text{–}1500 \text{ ml}}{4 \text{ breaths}}$ = 250–375 ml/breath

Back pressure is inherent with water displacement method of measuring breath volume. Findings, therefore, may be on low side of actual tidal volume — perhaps 350 ml instead of 500 ml.

The deep breath exhaled in Step E may well empty the jug completely. Therefore, the bucket should not be so full of water that it can't hold another jugful.

E. Now refill the jug with water and have your partner turn it upside down in the bucket. Insert the tubing as before. This time, take just one really deep breath, as deep as you can, and blow it all out into the tubing. Measure the volume of this deep breath to the nearest 100 ml.



After trying to empty the lungs completely, the average volume of air that remains, the residual volume, is about 1150 ml for females and 1500 ml for males (both adults at rest).

✓ 3–3. What was the volume of your deep breath?

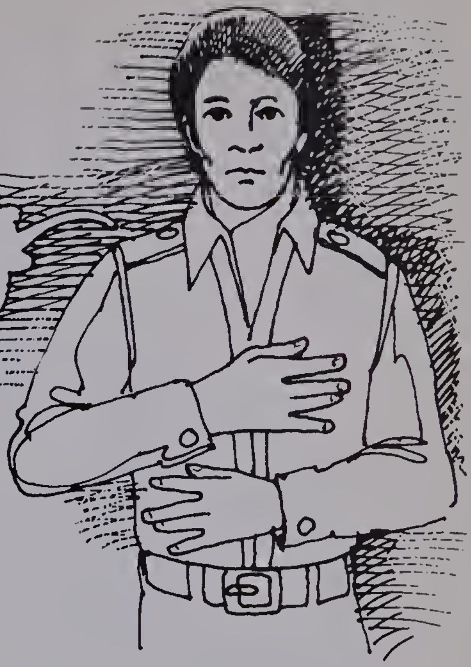
3-3. A typical range of values would be 1500 ml to 2500 ml of air.

Compare your answers to Questions 3–2 and 3–3. Surprised at the difference? Most people can breathe out a volume of air about seven times the volume of a normal breath. Even so, no matter how hard you try to empty your lungs completely, some air will be left. Your total lung capacity is about ten times the volume of a normal breath.

What causes air to move in and out of your lungs? Many people think it's caused by the ribs moving in and out. But this isn't the whole story.

Stand up. Place one hand on your chest and one hand on your abdomen just *above* your waist. Breathe normally and compare the amounts that both hands move.

Breathe Normally



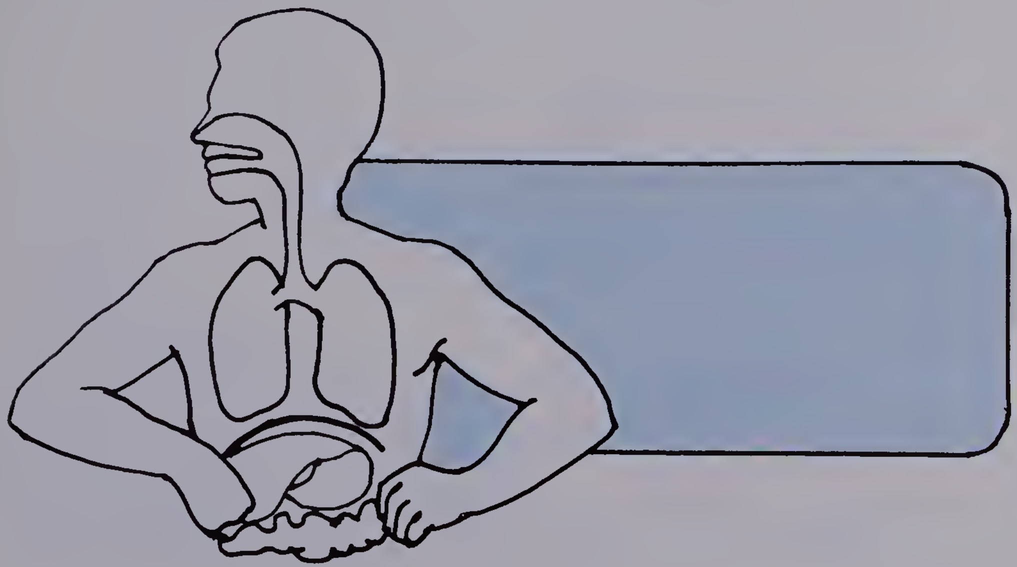
✓ 3–4. Which area seems to move more as you breathe, your chest or your abdomen? 3-4. Answers will vary.

Both your hands probably moved because both the diaphragm and the rib muscles are involved. But some people use one set of muscles more than the other. You could call some people "rib breathers" and some people "diaphragm breathers."

Diaphragm Breathing

The diaphragm lies just below the lungs. It separates the chest cavity, containing the lungs and heart, from the abdominal cavity, containing the stomach, liver, and intestines. When the diaphragm muscle contracts, the diaphragm loses some of its dome shape by flattening out.

Voice training increases use of the diaphragm, as does athletic training. Some research also suggests that rib breathing may be more typical of females, diaphragm breathing more typical of males.



✓ 3–5. When the diaphragm flattens, or moves downward, it puts pressure on the stomach and liver. What happens to the abdomen? 3-5. It is pushed out, or forward.

When the diaphragm flattens (Figure 3–1), pressure on the lungs is reduced. This is when inspiration, or breathing air in, occurs. With less pressure on the lungs, the lungs are able to hold more air. So air rushes in from the outside, through the mouth and nose, to fill the extra space in the lungs.

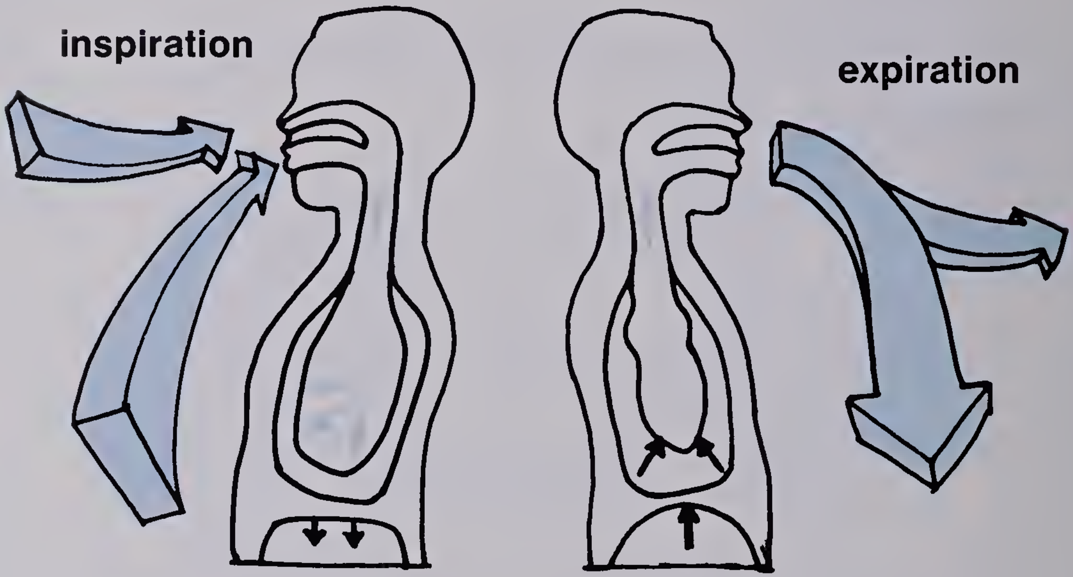
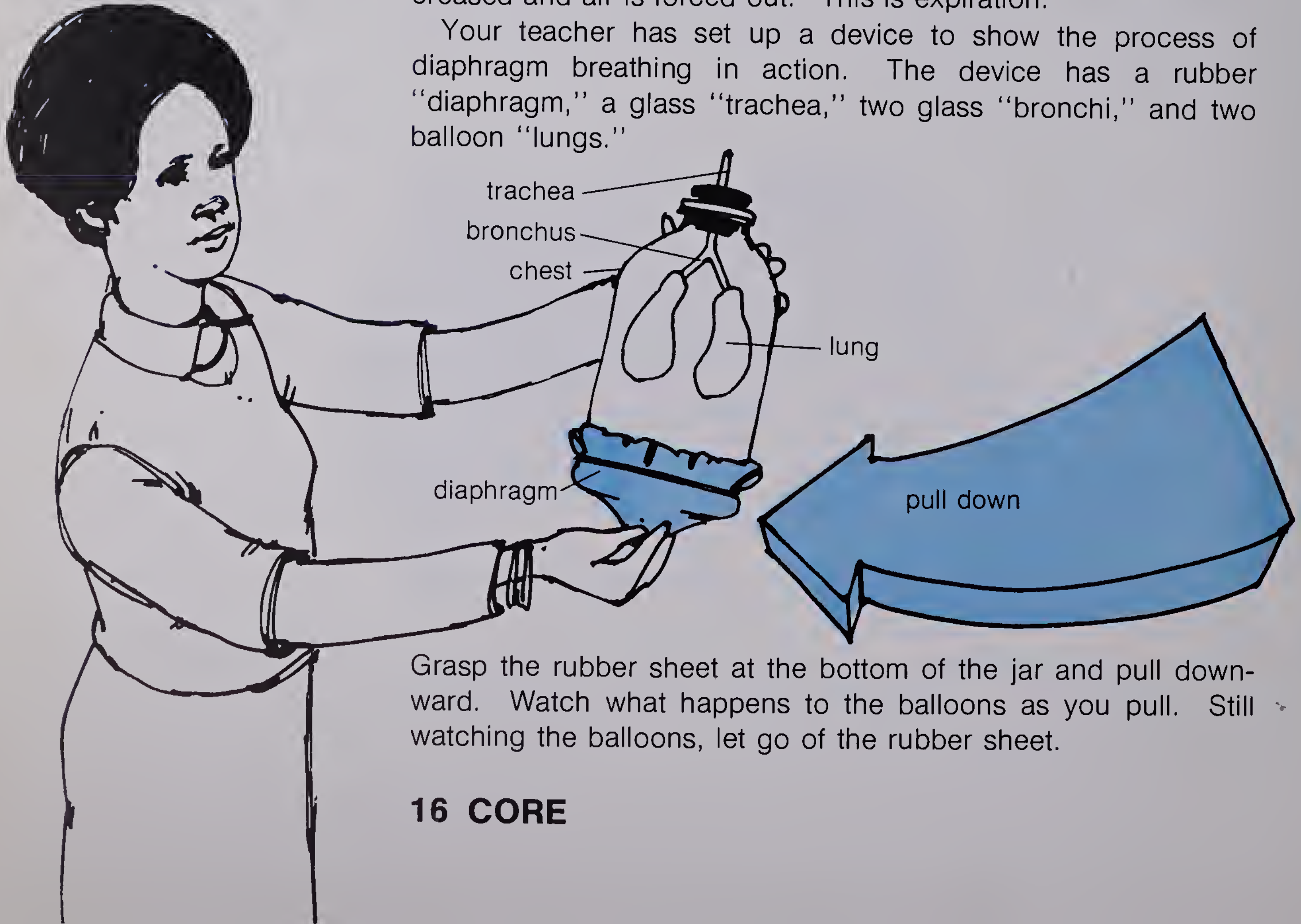


Figure 3–1

See Advance Preparation, p. TM 6, for details on assembling the diaphragm apparatus.

When the diaphragm muscle relaxes, the diaphragm goes back to its original dome shape. Pressure on the lungs is thus increased and air is forced out. This is expiration.

Your teacher has set up a device to show the process of diaphragm breathing in action. The device has a rubber "diaphragm," a glass "trachea," two glass "bronchi," and two balloon "lungs."



Grasp the rubber sheet at the bottom of the jar and pull downward. Watch what happens to the balloons as you pull. Still watching the balloons, let go of the rubber sheet.

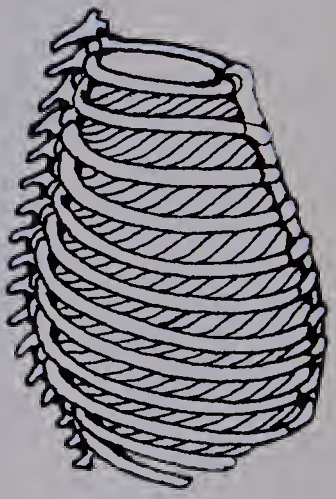
✓ 3–6. What happened to the balloons when you pulled the rubber sheet downward? When you let go?

3-6. Rubber sheet downward — balloons inflated, or took in air; rubber sheet let go — balloons deflated, or released air.

★ **3–7. Air moves in and out of your lungs because a moving diaphragm changes something. What does it change?**

3-7. The pressure on the lungs, or the pressure on the air inside the lungs.

Rib Breathing



Most people are rib breathers. Rib breathing affects the lungs in the same way as diaphragm breathing does. But now it's the movement of the rib cage rather than the diaphragm that makes a greater change in the pressure on the lungs.

The ribs are connected to both the backbone and the breastbone. Sets of muscles between the ribs can move the rib cage. When the rib cage moves up and out, there is less pressure on the lungs. Air rushes in to fill them. (See Figure 3–2.)

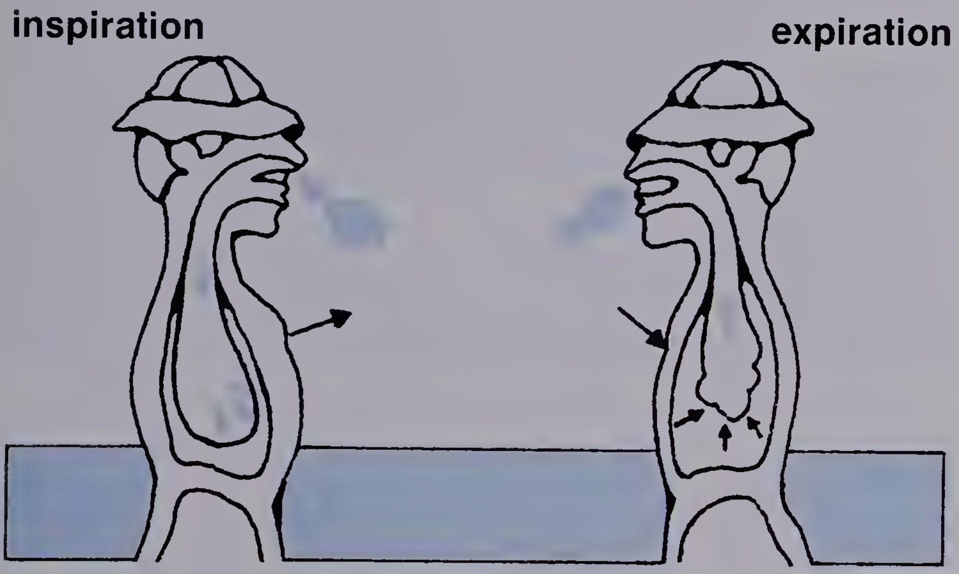


Figure 3–2

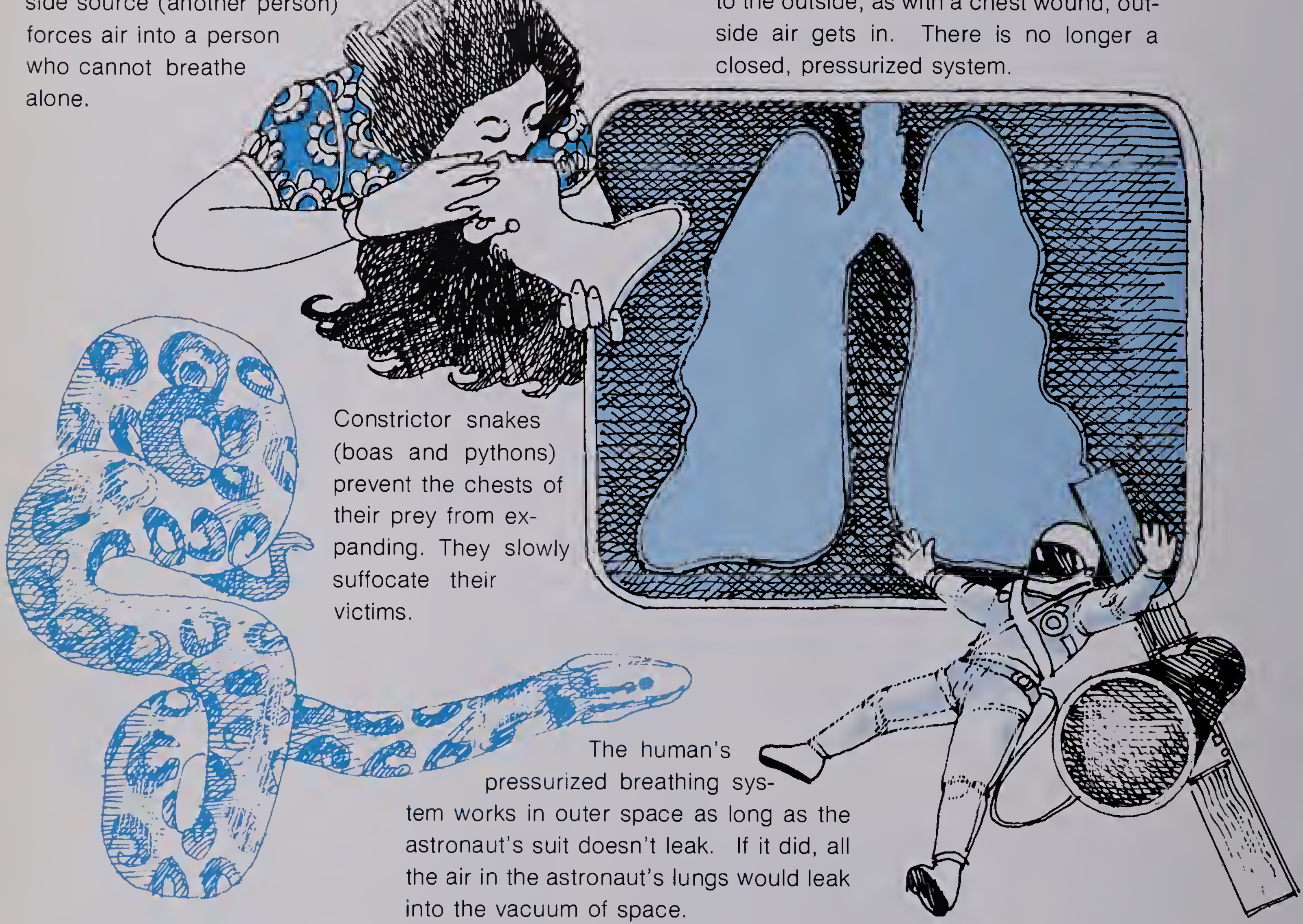
When the rib cage relaxes, or moves down and in, pressure on the lungs increases and air is forced out.

★ **3–8. When your rib cage moves up and out, what happens to the amount of air in your lungs?** 3-8. Amount of air increases — air is sucked in to fill extra room created in the lungs.

✓ 3–9. Which kind of breathing, diaphragm or rib, do you think results in a greater intake of air? Try to find out, then explain how you went about it.

3-9. Find some diaphragm breathers and some rib breathers (Question 3-4). Then collect their answers to Question 3-2 and compare the values. (Since people use both diaphragm and rib muscles during breathing, it's difficult to measure the actual contribution of each set of muscles.)

Knowing something about people's "pressurized breathing systems" will explain a few things.



Mouth-to-mouth resuscitation is possible because an outside source (another person) forces air into a person who cannot breathe alone.

Have you heard of "collapsed lungs"? When the chest cavity becomes opened to the outside, as with a chest wound, outside air gets in. There is no longer a closed, pressurized system.

Constrictor snakes (boas and pythons) prevent the chests of their prey from expanding. They slowly suffocate their victims.

The human's pressurized breathing system works in outer space as long as the astronaut's suit doesn't leak. If it did, all the air in the astronaut's lungs would leak into the vacuum of space.

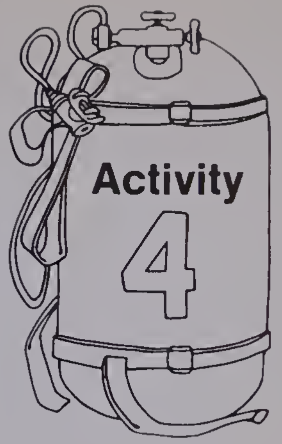
For interested students, the idea of pressurized air is revisited in Advanced Activity 11 in a discussion of Boyle's Law, and in Excursion Activity 13 in a discussion of air embolism and the bends.

A person's closed, pressurized system meets its match underwater, even if the person is in a diving suit. As a diver descends, the pressure of the water on the diver increases. This causes the pressure on the air the diver is breathing to be increased. The deeper a diver goes, the more pressurized, or compressed, the air becomes. At 100 metres underwater, the diver must work harder than at the surface to inhale the compressed air. At 1000 metres, inhalation is impossible.

✓ 3–10. Why do you think it's impossible to breathe compressed air at 1000 metres underwater?

3-10. The diaphragm and rib muscles aren't strong enough to push against, or expel, air at the high pressure existing at a 1000-metre depth.

Diagnosis



ACTIVITY EMPHASIS: Students use game *Diagnosis* to investigate causes, effects, symptoms, and treatments for the common cold, influenza, pneumonia, emphysema, asthma, chronic bronchitis, and carbon monoxide poisoning.

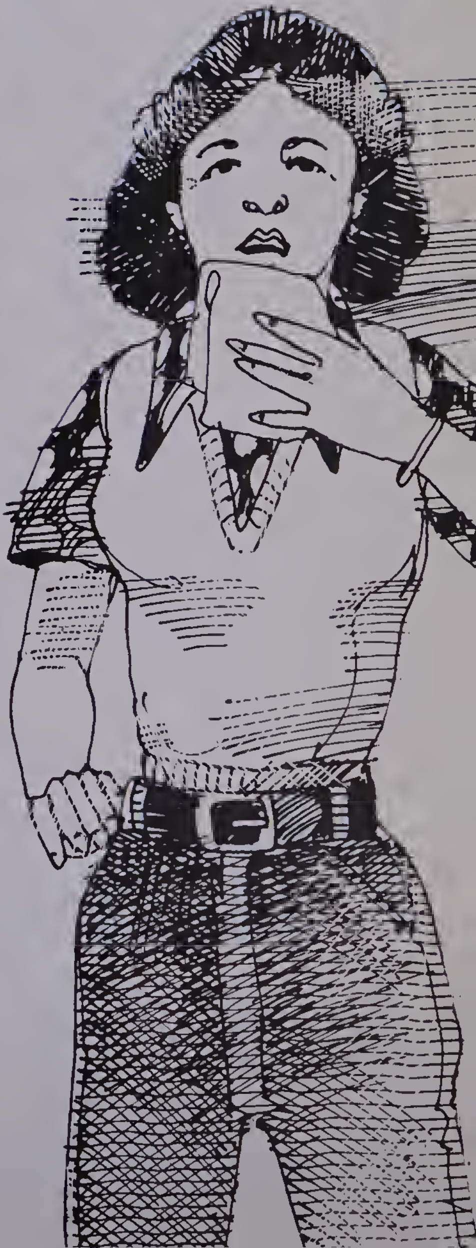
Even if you live out in the country, away from industry and traffic, the air you breathe is anything but clean. At the very least, you're inhaling particles of dust and pollen. And if you live in the city, you're probably getting particles of soot, metal, and rubber tires. You may even be inhaling small amounts of poisonous gases, such as carbon monoxide and sulfur dioxide.

Such dirt and gas invaders are products of our civilization. And they're not the only villains. Each breath you take also includes germs — bacteria and viruses. Most won't hurt you, but some will.

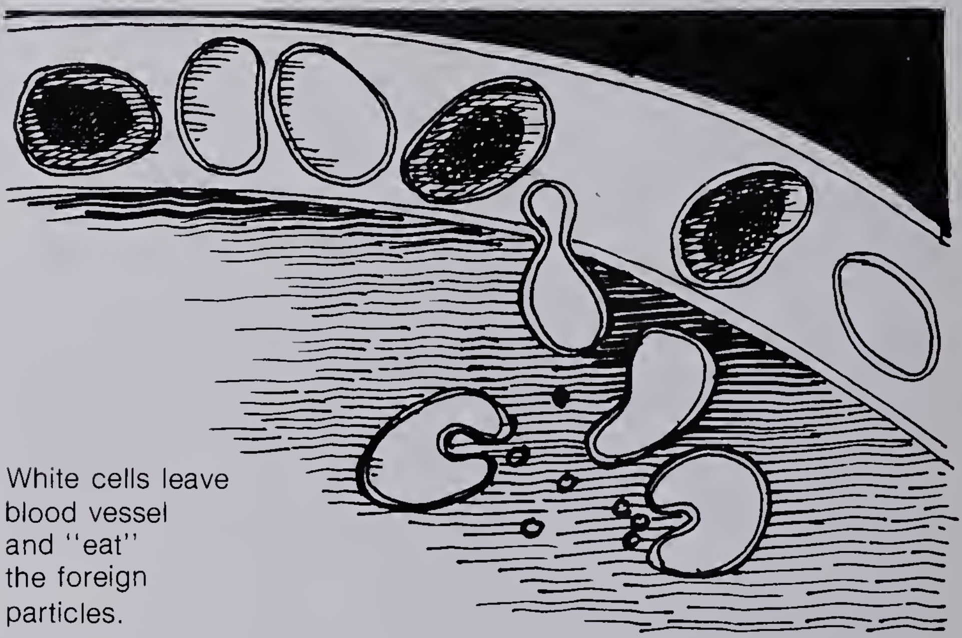
The human body does have several defense mechanisms to ward off or destroy invaders. One line of defense is the sticky mucus produced by cells in the breathing passages. The mucus traps most of the foreign particles brought in with the air. The dirty mucus is then coughed, sneezed, or swallowed out of the respiratory system.

MATERIALS PER STUDENT UNIT

game *Diagnosis: Getting Enough Oxygen,* consisting of "Rules," "Memory Card," and 9 "Patient's Cards"



Some invaders do get by this first line of defense and plunge deeper into the system. Other, internal defense mechanisms usually overcome the invaders. The blood's *white cells,* for instance, attack foreign material in the system. But sometimes the defense forces fail and an unhealthy condition develops.



White cells leave blood vessel and "eat" the foreign particles.

The invading particles may be germs that cause a cold, the flu, or pneumonia. They may be smoke or dust particles that can trigger asthma, bronchitis, or emphysema. Or, the invader may be something the body has no defense against at all — the killer gas carbon monoxide.

To learn more about what causes different respiratory conditions and what can be done about them, you will need the following:

Students may need to be reminded when they finish the game that they are still not doctors; they only have a better awareness of respiratory conditions than they had before.

a partner
blank paper for keeping score
game *Diagnosis: Getting Enough Oxygen,*
  consisting of "Rules,"
  "Memory Card,"
  9 "Patient's Cards"

The game will probably take two or three class periods to play, so plan your time to allow for it. Begin by reading the rules. After you have played the game, answer these questions.

4-1. Cold, flu, viral pneumonia.

★ 4-1. Name three respiratory conditions for which only the symptoms and not the causes can be treated.

4-2. Membranes in the nose secrete more mucus than normal.

★ 4-2. What causes a runny nose when you have a cold?

★ **4-3. Why can influenza be dangerous?**

★ **4-4. If you smoke, what respiratory diseases do you have a greater chance of developing than a nonsmoker?**

★ **4-5. How can carbon monoxide poisoning be prevented?**

★ **4-6. Match the letter of each condition with the number that best tells its symptom or symptoms.**

1**a. Common cold**
7**b. Influenza**
2**c. Bacterial pneumonia**
6**d. Emphysema**
3**e. Asthma**
4**f. Chronic bronchitis**
5**g. Carbon monoxide poisoning**

1. Taste and smell dulled
2. X ray shows dark patches on lungs
3. Wheezing attacks
4. White or yellow sputum
5. Unconsciousness
6. Shortness of breath with mild exercise
7. Muscles ache in back and limbs

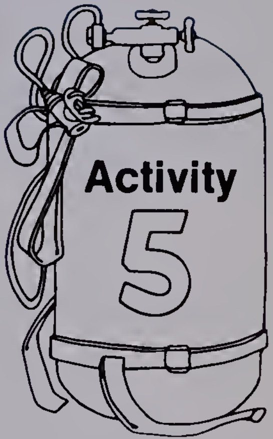
4-3. It can weaken someone to the point where the person can't resist other infections.

4-4. Chronic bronchitis and emphysema.

4-5. Don't get caught in a closed environment with anything burning, including gasoline in a car. Allow plenty of ventilation.

MATERIALS PER STUDENT UNIT

assembled respiration apparatus (see Advance Preparation, p. TM 6)
graduated cylinder, 100-ml
limewater, 100 ml
soda straw
scissors (to cut straw)
cellophane tape

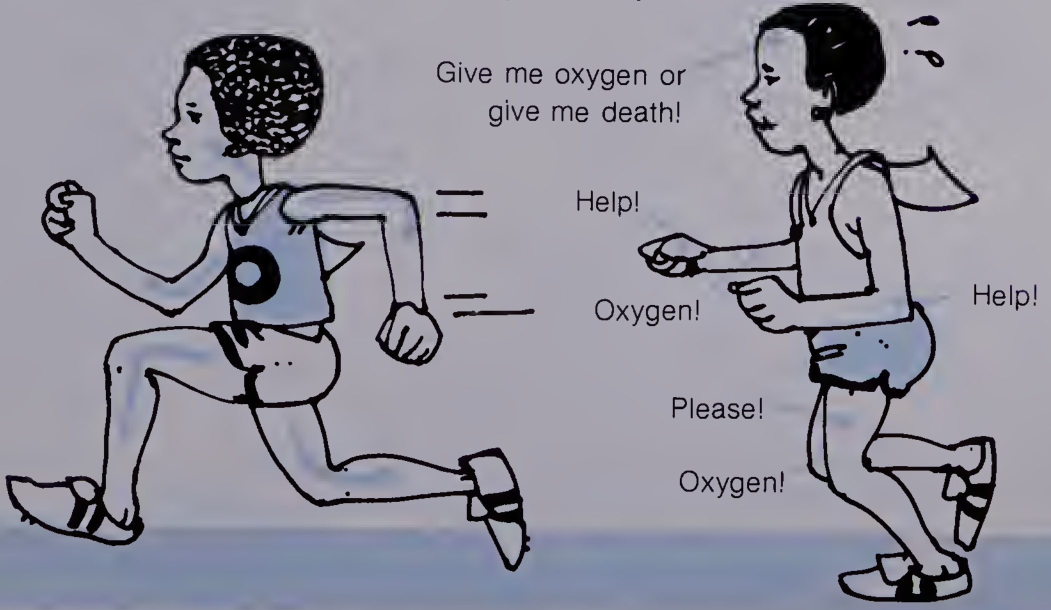


At Cell Level

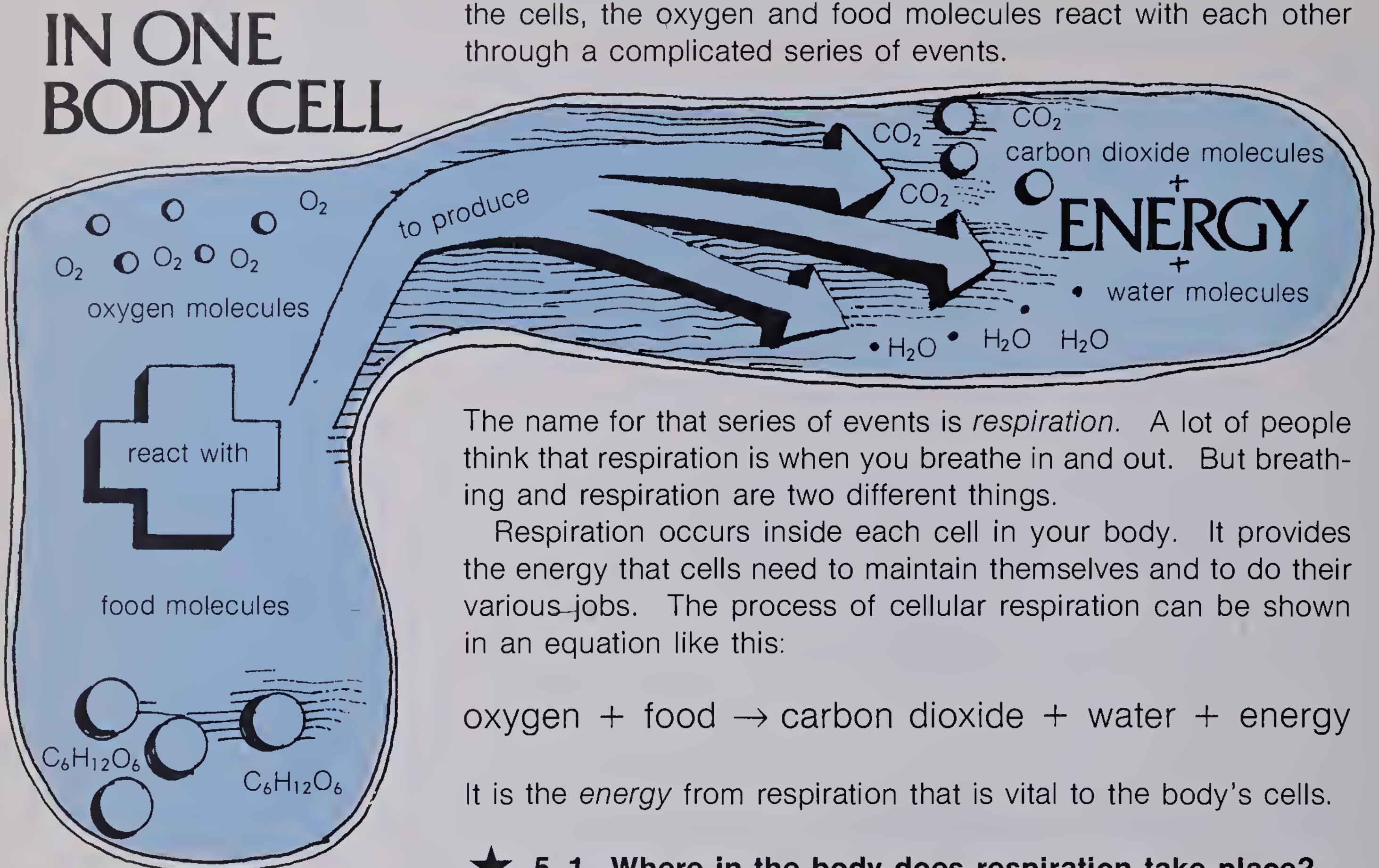
ACTIVITY EMPHASIS: The energy-producing process of respiration occurs in each body cell. Cells get oxygen and food via the blood. And the blood carries away the waste carbon dioxide.

Think of all the cells in your body. You have brain cells and muscle cells. You have heart cells and bone cells. You have skin cells, lung cells, stomach cells, and liver cells. Every cell in your body needs oxygen to stay alive.

Getting oxygen to your cells begins by getting air into your lungs. Once air is in the lungs, the particles, or molecules, of oxygen can pass out of the lungs and into the bloodstream. The blood carries the molecules of oxygen to your body cells.


Give me oxygen or give me death!
Help!
Oxygen!
Help!
Please!
Oxygen!

Blood also brings food molecules to your cells. Once inside the cells, the oxygen and food molecules react with each other through a complicated series of events.



The name for that series of events is *respiration*. A lot of people think that respiration is when you breathe in and out. But breathing and respiration are two different things.

Respiration occurs inside each cell in your body. It provides the energy that cells need to maintain themselves and to do their various jobs. The process of cellular respiration can be shown in an equation like this:

$$\text{oxygen} + \text{food} \rightarrow \text{carbon dioxide} + \text{water} + \text{energy}$$

It is the *energy* from respiration that is vital to the body's cells.

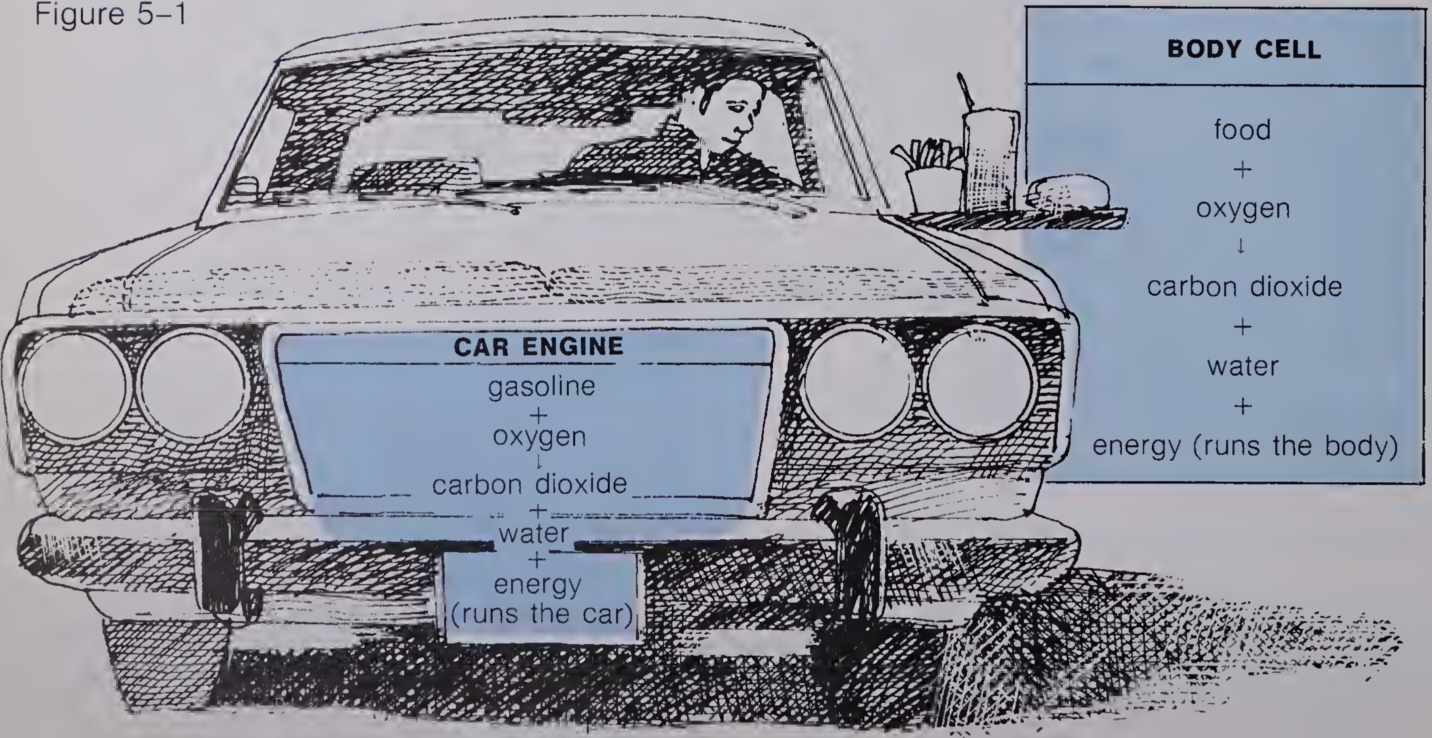
For interested students, Advanced Activity 10 gives a more detailed (and more difficult) look at cellular respiration.

★ **5–1. Where in the body does respiration take place?**

5-1. Within each cell in the body.

As you can see in Figure 5–1, the process of respiration is something like what happens in a car engine. In both systems, useful energy comes from a fuel (gasoline or food). Both systems need oxygen to work. And both systems produce carbon dioxide and water in addition to energy.

Figure 5–1



Carbon dioxide is not useful to the body's cells, so the cells get rid of it. The gas is sent into the bloodstream, returned to the lungs, and breathed out of the body. You can see this for yourself with the following equipment:

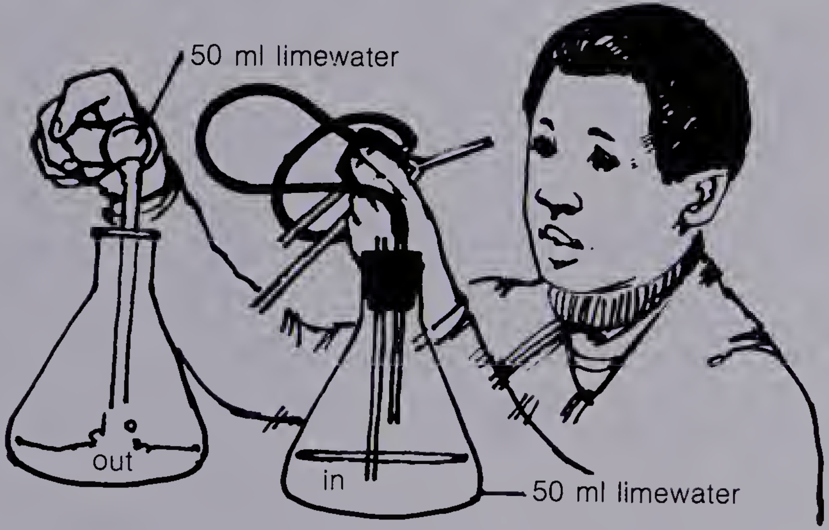
respiration setup labeled *Getting Enough Oxygen, Activity 5*
graduated cylinder, 100-ml
limewater
soda straw, 3–4 cm
cellophane tape

See Advance Preparation, p. TM 6, for details on assembling the respiration setup.

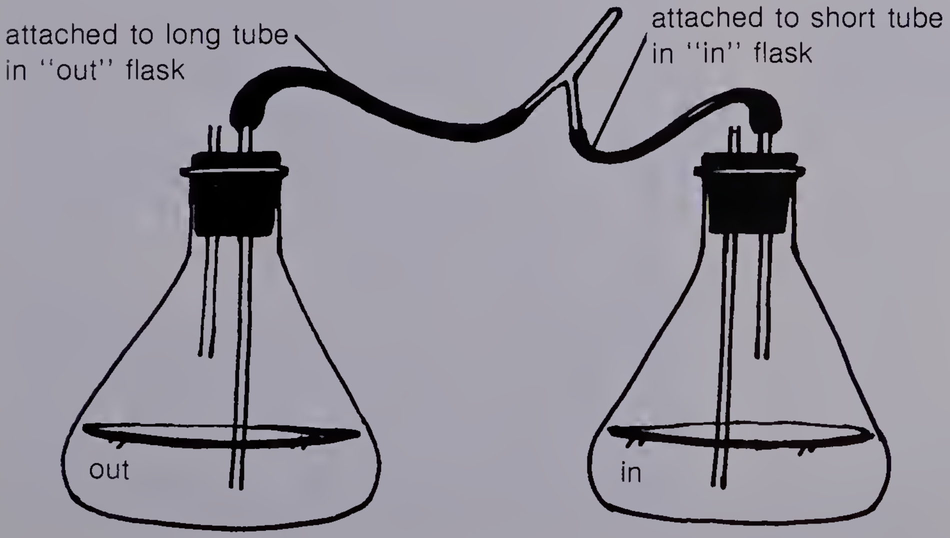
One thing you need to know for this investigation is that carbon dioxide gas makes clear limewater turn milky.

A. Put 50 ml of limewater into each flask. Put the stoppers back into the flasks.

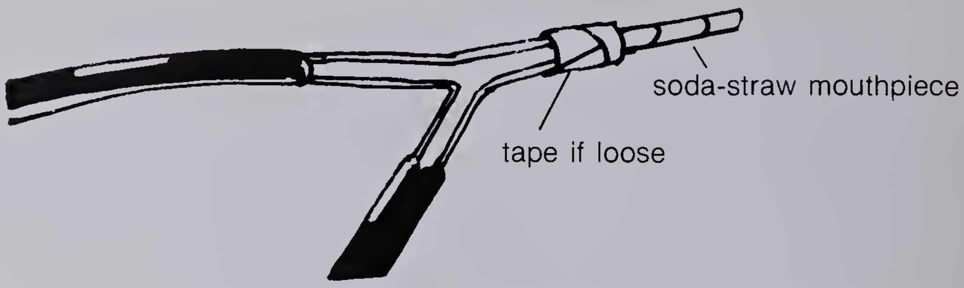
Limewater is a saturated solution of calcium hydroxide. See Advance Preparation, p. TM 7, for details. If you wish, you could substitute water containing an indicator such as brom thymol blue, which turns a light yellow in the presence of CO_2.



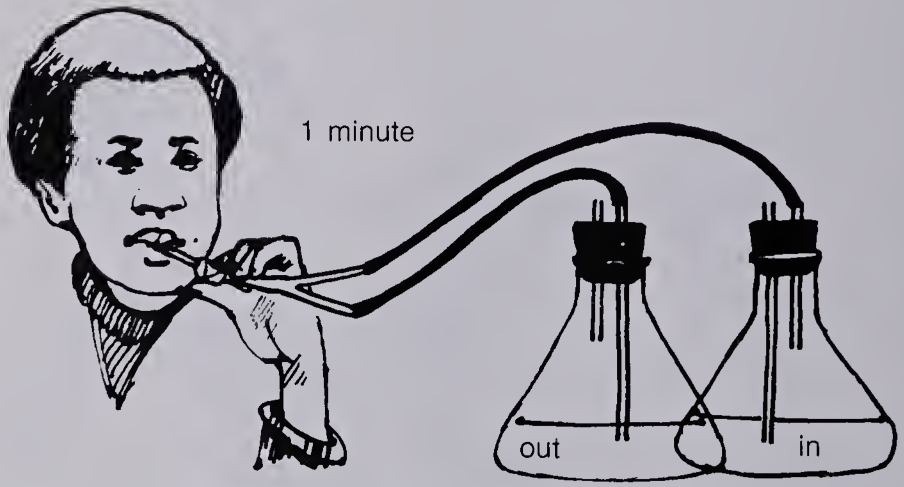
B. Check that the rubber tubing is attached to the glass tubes as shown.


attached to long tube in "out" flask
attached to short tube in "in" flask
out
in

C. Insert the short soda straw into the end of the Y-shaped glass tube. The straw will serve as a mouthpiece. If the straw is loose in the tube, seal it with tape.



D. Breathe in and out through the mouthpiece for about one minute. Observe what happens in both flasks. Then discard the soda-straw mouthpiece.



✓ 5–2. Describe what happened in both flasks.

5-2. "In" flask — bubbles, but nothing happened to the limewater; "out" flask — bubbles, and limewater turned milky.

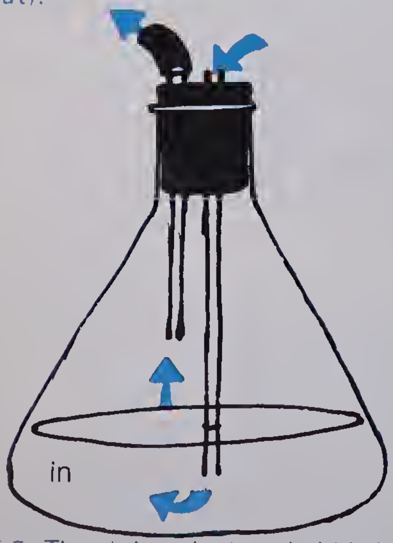
✓ 5–3. Study the way the apparatus was put together. What do you think the labels *in* and *out* refer to on the flasks?

5-3. The limewater in the "in" flask bubbled when students inhaled (breathed *in*). The limewater in the "out" flask bubbled when students exhaled (breathed *out*).

The air that you breathe into your lungs is a mixture of gases. You know it contains oxygen. It also contains a small amount of carbon dioxide. When you breathed in through the mouthpiece, you took air from the "in" flask. This allowed outside air to enter through the long tube, bubble through the limewater, and fill the flask.

✓ 5–4. Does air contain enough carbon dioxide to turn clear limewater milky? 5-4. No.

✓ 5–5. Explain what happened in the flask labeled *out*.

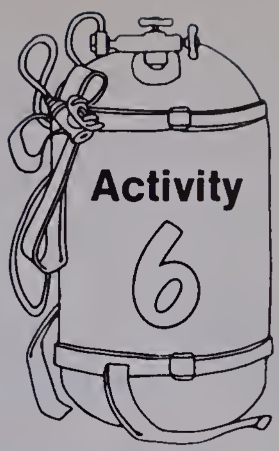


5-5. The air breathed out bubbled through the limewater. The exhaled breath contained enough carbon dioxide to turn the limewater milky.

★ **5–6. As a review, write the reaction for respiration.**

5-6. oxygen + food ⟶ carbon dioxide + water + energy

ACTIVITY EMPHASIS: Warning signs for insufficient oxygen; the main steps in mouth-to-mouth resuscitation.



Handling Breathing Emergencies

MATERIALS PER STUDENT UNIT
None.

Suppose you got caught in the following situation, where you need to keep someone breathing until medical help arrives. The best way to do that is by mouth-to-mouth resuscitation.

The sun is out and the water's beautiful. You and your friend are snorkeling in shallow water, watching the fish and the plants sparkle in the light.

Suddenly, your friend starts coughing and struggling in the water. You swim over to see what's wrong as your friend starts to go under.

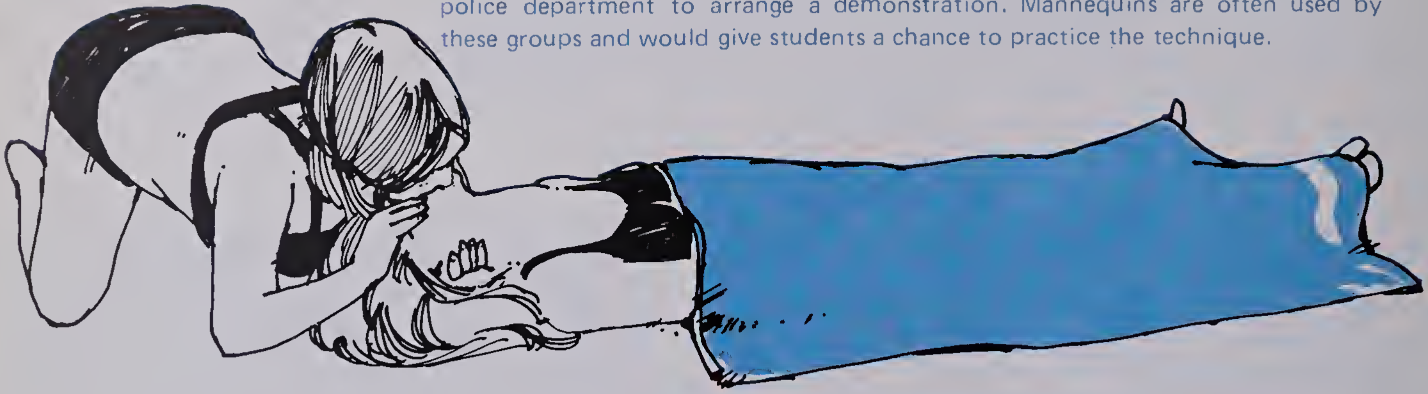
Luckily, you're in shallow water. You can stand up and get her above water quickly.

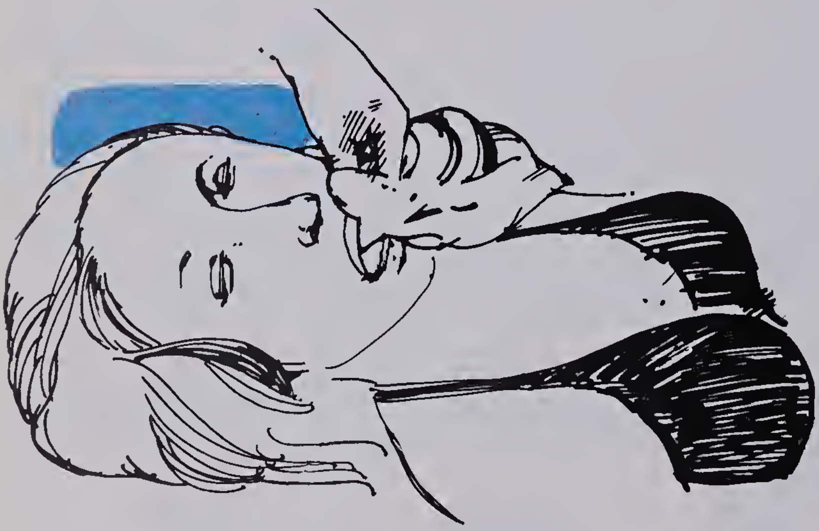
But after dragging her ashore, you realize she's not breathing. Without air, she'll die in six minutes or less.

This activity could serve as the basis for a large-group exercise on fundamental first aid. Also, a homemade training device is described in Advance Preparation on p. TM 8. You may deem this device preferable to the use of live "victims."

Study each of the following steps carefully. You may want to work with a partner and practice the procedure. In a real emergency, getting air into the victim is more important than cleanliness. But in practicing, just pretend to do Steps 1 and 4.

You may wish to contact the local Heart Association, Red Cross, or, possibly, the police department to arrange a demonstration. Mannequins are often used by these groups and would give students a chance to practice the technique.



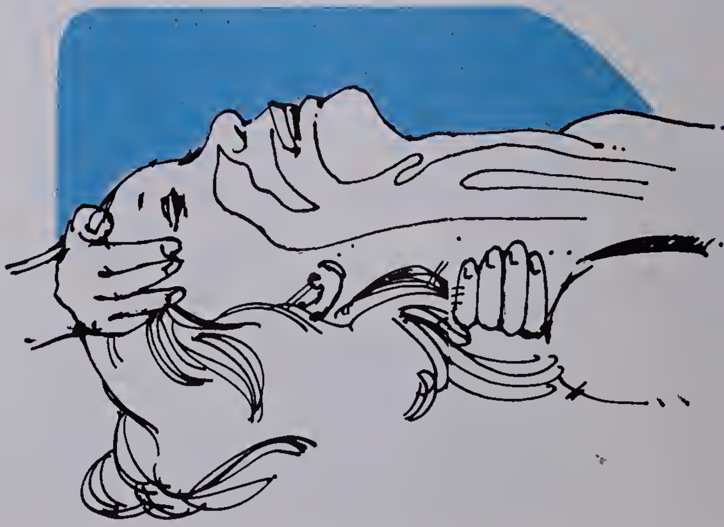


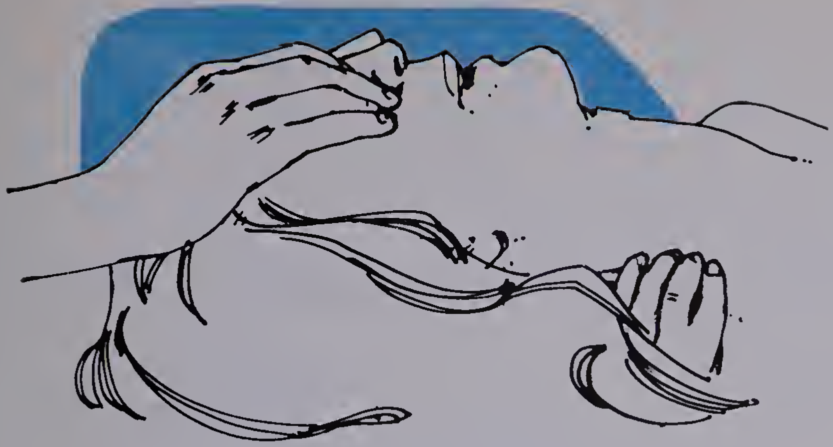
1. Clear the mouth.

Place the victim on his or her back. Wipe any foreign material out of the victim's mouth. Clear the mouth as fast as possible.

2. Keep the head in this position throughout.

Place the heel of one hand on the victim's forehead. Place the other hand under the victim's neck and lift upward. Tilt the head back so the chin points upward and the mouth is open.



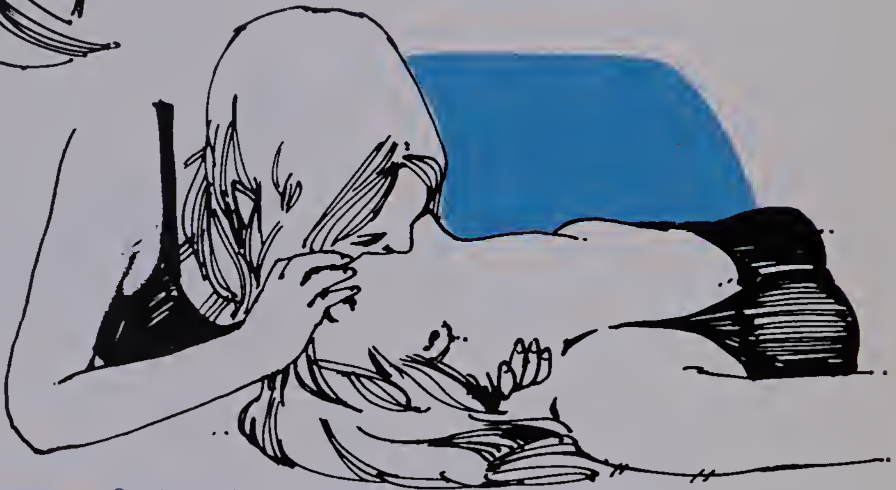


3. Pinch the nose closed.

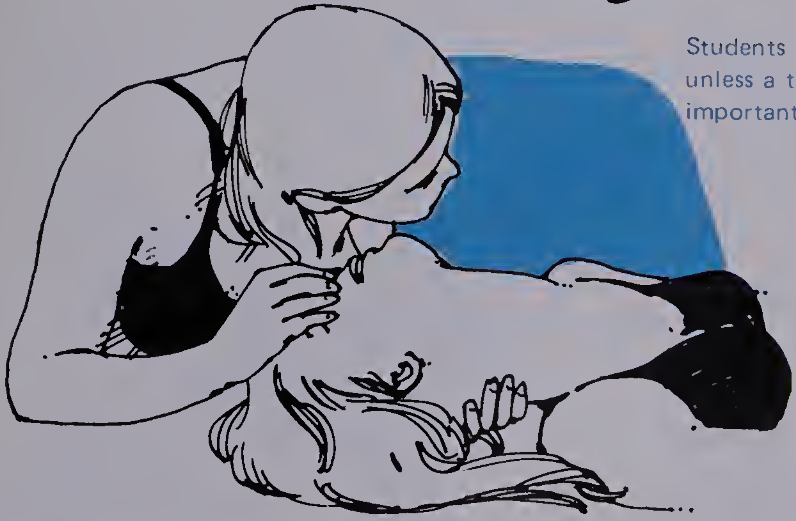
With the hand that is pressing on the victim's forehead, use the thumb and index finger to pinch the victim's nostrils closed. For a small child, your mouth should cover the victim's nose and mouth.

4. Blow air into the mouth.

Take a deep breath. Seal your wide-open mouth over the victim's mouth and blow. Don't blow as hard for a small child as for an adult. Watch for the victim's chest to expand.



Students should not actually blow air into the "victim's" mouth unless a training device is being used. Practice up to this point is important, however.



5. Listen for victim to breathe out.

Stop blowing when the victim's chest has expanded. Turn your head and listen and watch for the victim to breathe out.

6. Quickly blow in four more breaths.

Repeat the breathing process every 5 seconds for an adult, every 3 seconds for a child. Keep this up until medical help arrives or until the person starts to breathe normally again.

★ **6–1. The first step in mouth-to-mouth resuscitation is to remove any foreign material from the victim's mouth. Why?** 6-1. So that the trachea won't become clogged when breaths are forced into the victim.

✓ 6–2. Compare Figure 6–1 with the person whose head is tilted back in Step 2 (page 26). Why should the head be tilted back throughout the procedure?
6-2. So that the tongue won't block the opening to the trachea.

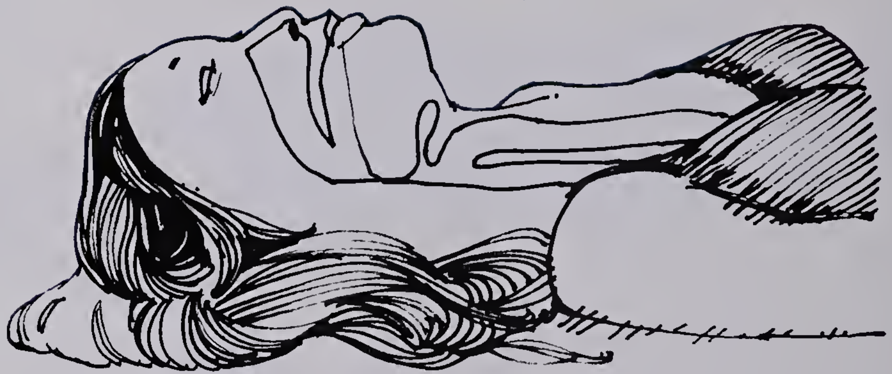
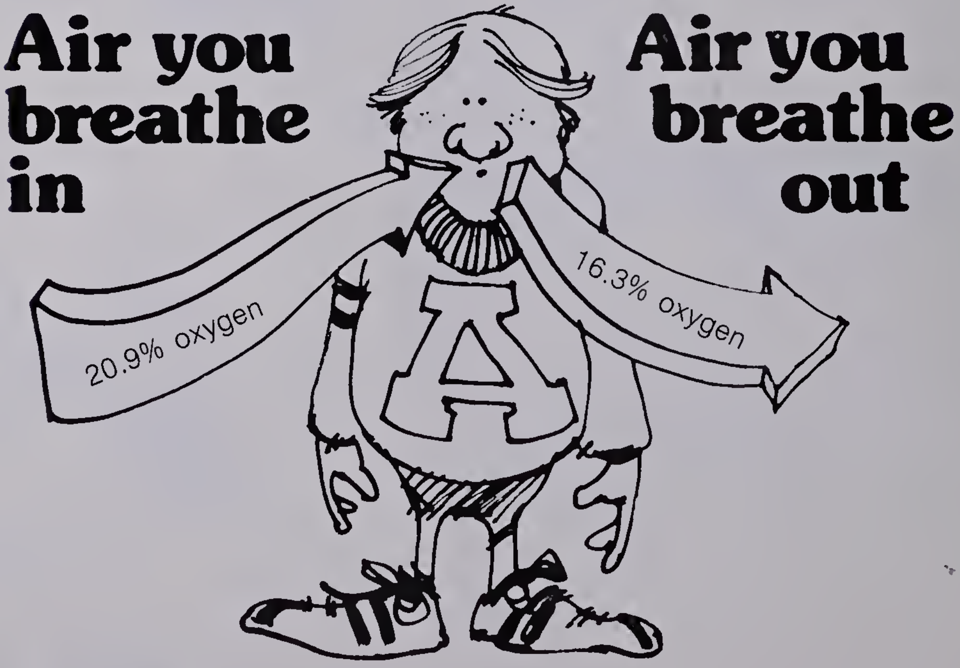


Figure 6–1

★ **6–3. During mouth-to-mouth resuscitation, why is it necessary to pinch the victim's nostrils closed while you blow air into the mouth?** 6-3. So that all the exhaled air is forced to the victim's lungs and not lost through the nasal passageway.

✓ 6–4. When you inhale, your own body takes oxygen out of the air that you've breathed in. When you blow out again, is there enough oxygen left to help the victim? Explain your answer. (Hint: The picture will give you a clue.)

6-4. Yes. A large amount of the oxygen breathed in (about 78%) is also breathed out. This method is successful precisely because there is enough oxygen left.



Drowning is only one reason why people stop breathing. Other causes include heart failure, drug or gas poisoning, blockage of the air passages, disease, smothering, strangulation, and electric shock. Whatever the cause, the signs are the same when someone isn't getting any oxygen.

Death by drowning is the topic of Excursion Activity 16. The resuscitation technique generalized in the present activity has a few variations when a drowning victim is involved.

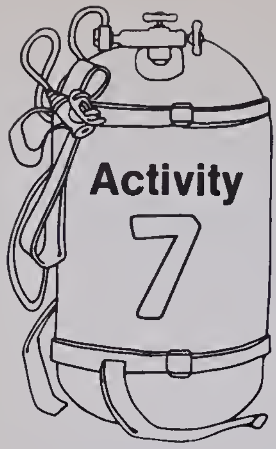
Someone Needs Oxygen!

eye pupils remain dilated (large) in light
tongue, lips, fingernails turn blue
loss of consciousness
breathing movements stop

Every second lost in getting oxygen to a victim increases the chance of permanent injury. Know what you need to do and act fast.

★ 6-5. Suppose you came upon a person passed out on the ground. How would you decide if it was a breathing emergency?

6-5. Check for: blue color in lips, fingernail beds, and tongue; loss of consciousness; pupil dilation; absence of breathing movements.



Do You Control Your Breathing?

ACTIVITY EMPHASIS: Breathing rate is under both voluntary and involuntary control. Carbon dioxide level in blood triggers involuntary feedback mechanism. Use of hyperventilation to circumvent feedback control during swimming can be dangerous.

MATERIALS PER STUDENT UNIT
watch or clock with second hand
paper bag, 1-litre
Resource Unit 13

In a TV interview, a diver who almost drowned while exploring an underwater cave was asked, "How did you manage to hold your breath so long?" "I had two choices," she said, "hold my breath or drown."

She wasn't joking. Consider divers whose air supply runs out before they can surface. Caught without air long enough, the divers can't resist the natural urge to breathe. So they do breathe, but it's a lungful of water. Most diving deaths are caused by drowning.

How long can you hold your breath? Try it now as you read. Take a deep breath and hold it as long as you can. You can resist breathing for a while. But before long, the need to breathe gets too strong. Can you feel the tightness building up?

Don't overdo it!
Stop as soon as
you need to breathe.

Your body's own control mechanism will soon take over and force you to breathe, no matter how hard you try not to. It's a natural reflex, like blinking.

Blinking Reflex

Shivering Reflex

✓ 7–1. Describe what happened to you as you held your breath.

✓ 7–2. Do you think it's possible for people to commit suicide by holding their breath? Explain your answer.

7-1. Student may note a sequence of events such as this: warm feeling, increase in pulse rate, lungs felt like bursting, finally forced to breathe.

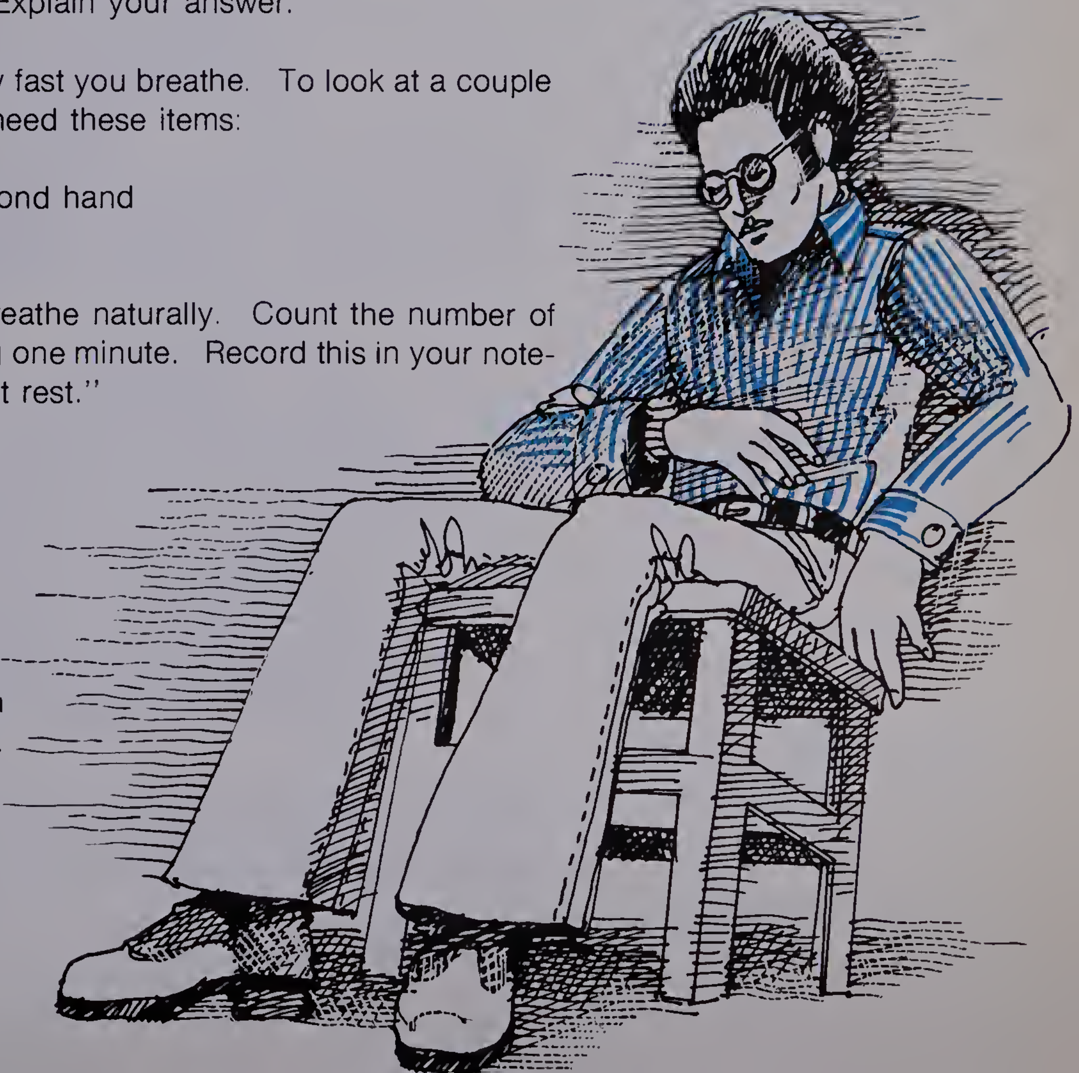
7-2. No. The body's natural control will take over and make a person breathe.

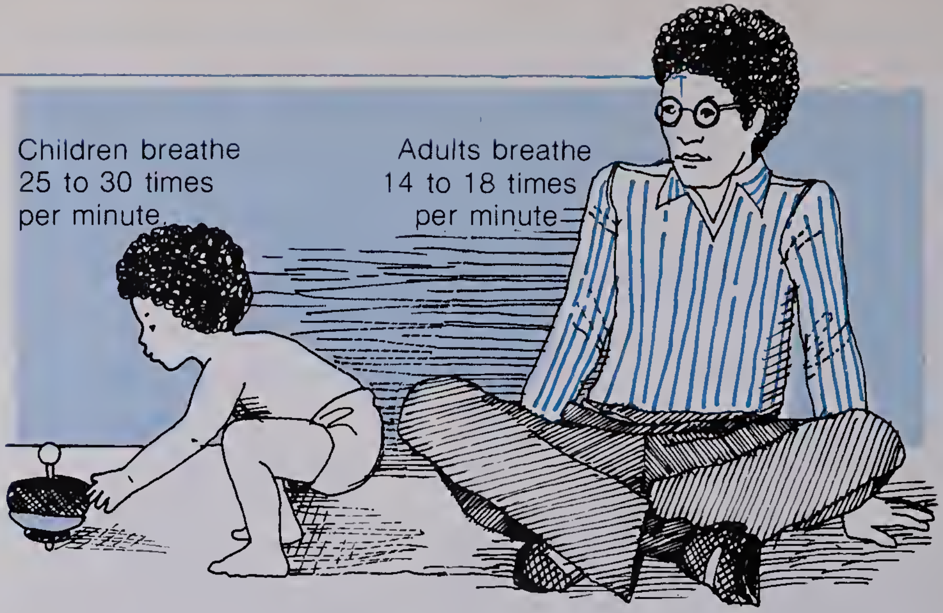
Several factors control how fast you breathe. To look at a couple of those factors, you will need these items:

watch or clock with second hand
small paper bag

A. Sit down, relax, and breathe naturally. Count the number of breaths you take during one minute. Record this in your notebook as your count "at rest."

At Rest

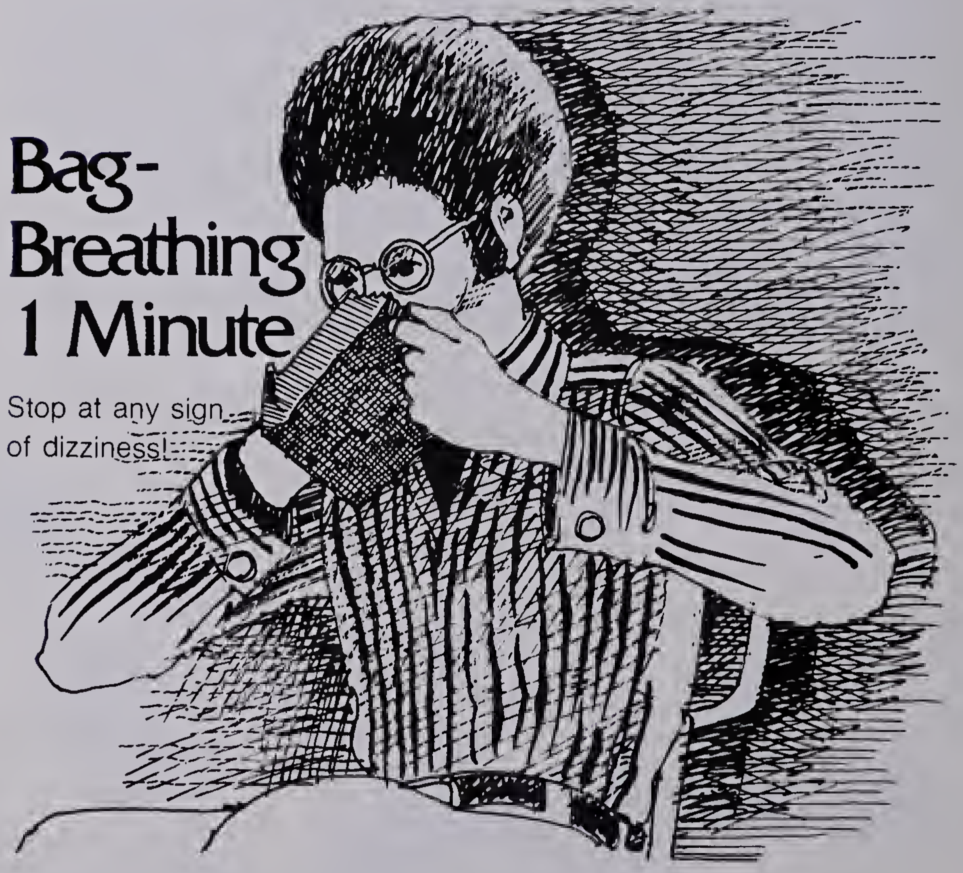



Children breathe 25 to 30 times per minute.
Adults breathe 14 to 18 times per minute

✓ 7–3. Sitting quietly, how does your rate of breathing compare with that of most adults? 7-3. Probably slightly faster.

Only a rough count is possible with the bag-breathing method. Students may need to bag-breathe for two minutes to get any results. But if so, caution them not to go beyond two minutes and to stop at any sign of dizziness before then. Fast, deep breathing should also be discouraged.

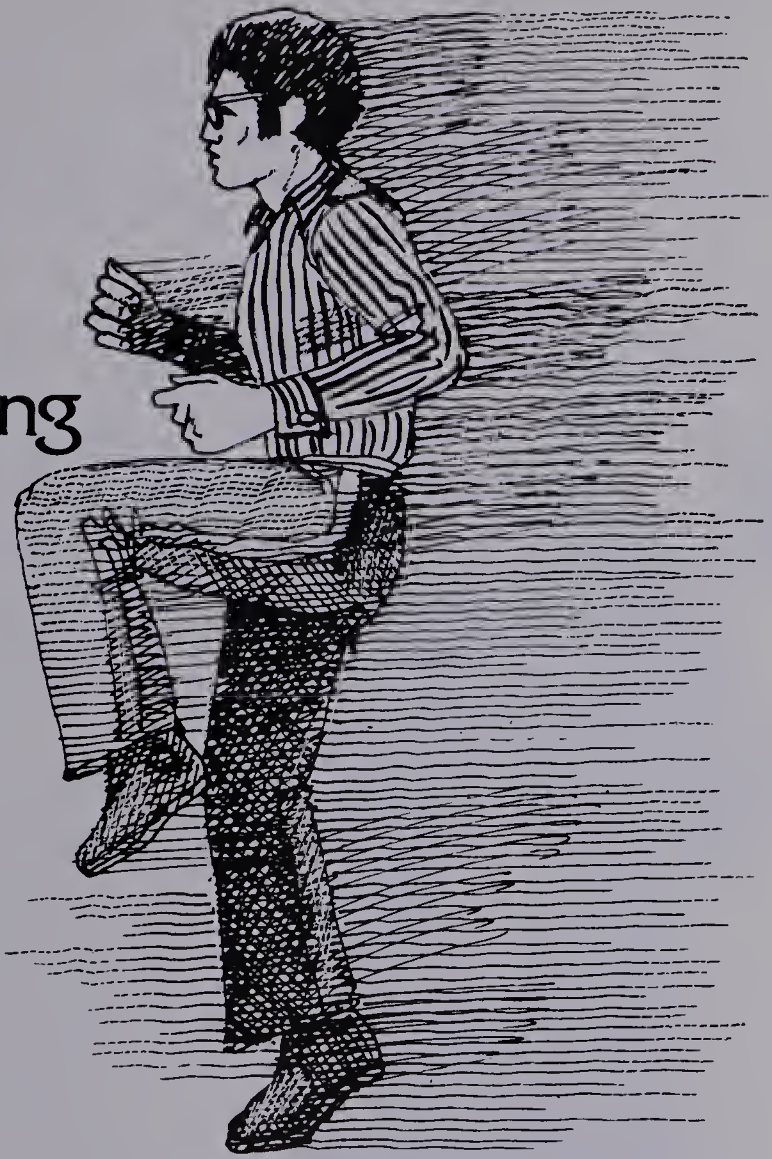
B. Still sitting, hold a small paper bag over your nose and mouth. Breathe into it for one minute, then remove the bag. Right away, count how many breaths you take in one minute. Record this as your count "after bag-breathing."


Bag-Breathing 1 Minute
Stop at any sign of dizziness!

If you wish, you may have students substitute breath-holding for bag-breathing.

✓ 7–4. After breathing into the bag, were you breathing faster or slower than your normal rate (Step A)? 7-4. Faster.

C. Run rapidly in place for one minute. Then keep running for another minute while you count the number of breaths you take. Record this as your count "while running."



Running

Bag-breathing and running changed your breathing rate automatically. You didn't have to think about changing; your *involuntary* control system did it for you. In other words, you did not consciously control what was happening.

But you know you can also change your breathing rate on purpose. You can hold your breath (for a while). You can take short breaths or long breaths, deep ones or shallow ones. So your breathing is also under a *voluntary* control system — you can consciously control it.

✓ 7–5. Name some situations where you aren't thinking about breathing and your involuntary control system is at work.

7-5. Sleeping, deep in thought, unconscious, reading or involved in some other activity, and so on.

7-6. No. People can't stop breathing for long, nor can they breathe slowly, for instance, when they're "out of breath."

✓ 7–6. Can you always control your breathing rate if you want to? Explain your answer.

When you try to hold your breath but finally have to give in to the urge to breathe, it's because your involuntary control system has taken over. How does the involuntary control system know when it's needed? The clue is in the air itself.

Look at Figure 7–1. It shows the major gases in the air you breathe in and out. (Neither side adds up to 100% because water vapor and other minor gases have not been included.)

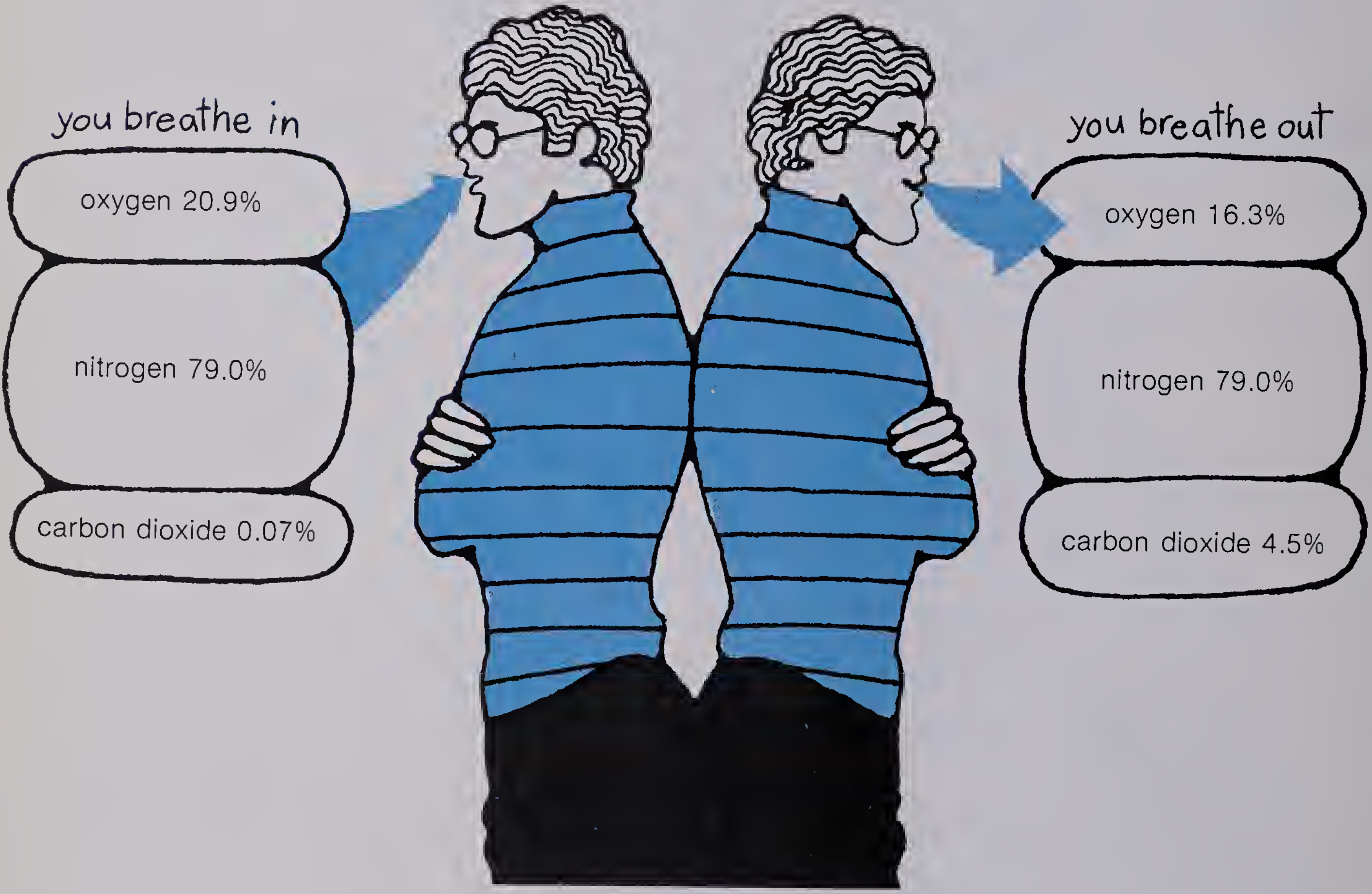


Figure 7–1

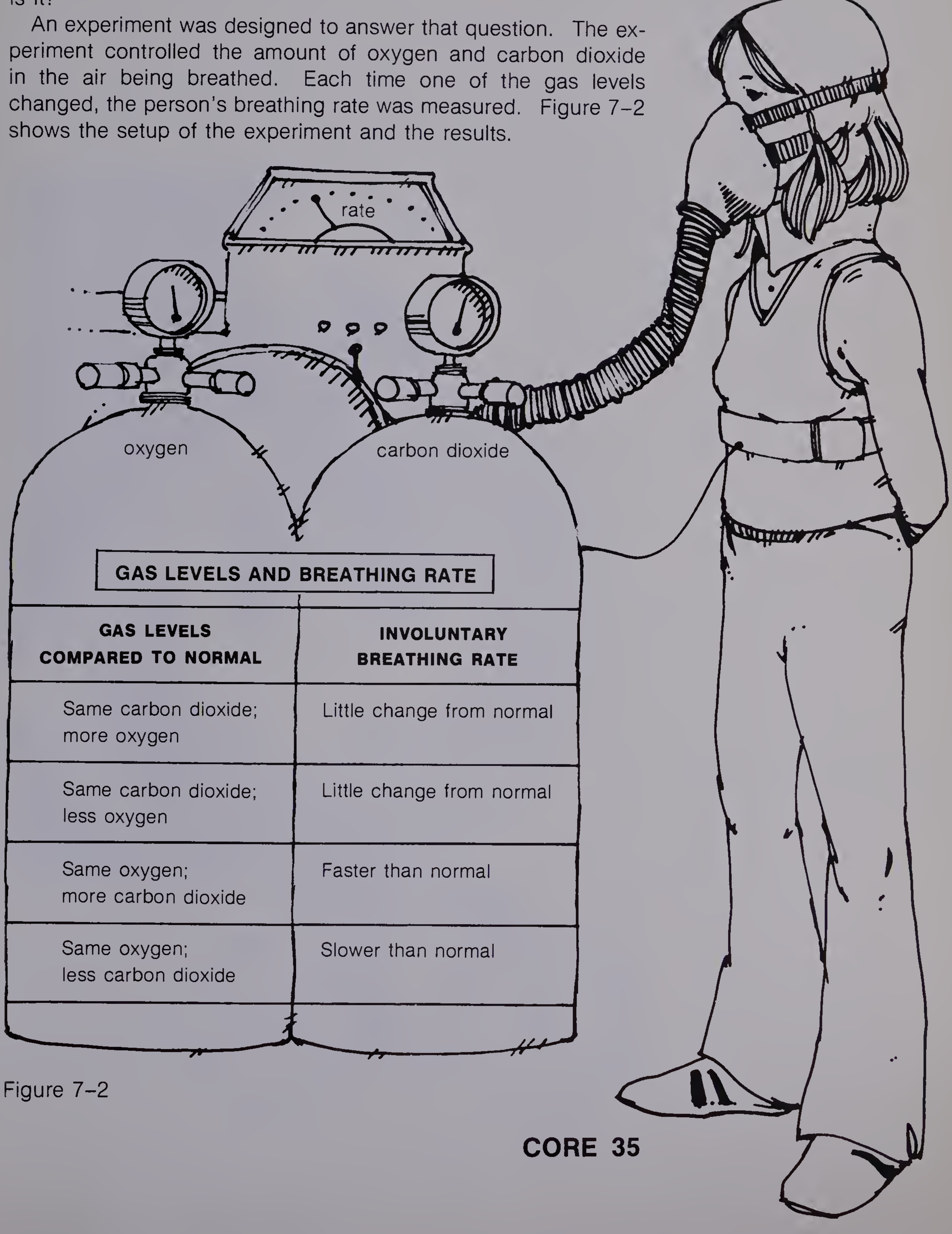
You can see that your body changes the air you breathe. It removes some of one gas and adds some of another.

✓ 7–7. Which gas does your body need from the air you inhale? (Which percentage goes down?) 7-7. Oxygen.

✓ 7–8. Which gas does your body get rid of when you exhale? (Which percentage goes up?) 7-8. Carbon dioxide.

Now you might have an idea about what triggers your involuntary control system. There are two possibilities: (1) a change in the amount of oxygen in your lungs and blood, or (2) a change in the amount of carbon dioxide in your lungs and blood. But which is it?

An experiment was designed to answer that question. The experiment controlled the amount of oxygen and carbon dioxide in the air being breathed. Each time one of the gas levels changed, the person's breathing rate was measured. Figure 7–2 shows the setup of the experiment and the results.



GAS LEVELS AND BREATHING RATE

GAS LEVELS COMPARED TO NORMAL	INVOLUNTARY BREATHING RATE
Same carbon dioxide; more oxygen	Little change from normal
Same carbon dioxide; less oxygen	Little change from normal
Same oxygen; more carbon dioxide	Faster than normal
Same oxygen; less carbon dioxide	Slower than normal

Figure 7–2

★ 7–9. Based on the results in Figure 7–2, which gas seems to control your involuntary breathing rate?

7-9. Carbon dioxide.

Normally, the CO_2 buildup is what causes an increased breathing rate. But a low oxygen level can cause the same result if the deficit is greater than 10%.

Most people would guess that a low oxygen level is why you can't hold your breath very long. But it's really a buildup of carbon dioxide in your lungs and blood that has the greater effect on your breathing rate.

You have a breathing control center in your brain (Figure 7–3). It receives information, or *feedback*, from many parts of the body. It senses especially how much carbon dioxide is in your blood.

Have *Resource Unit 13* available to aid students in understanding feedback systems.

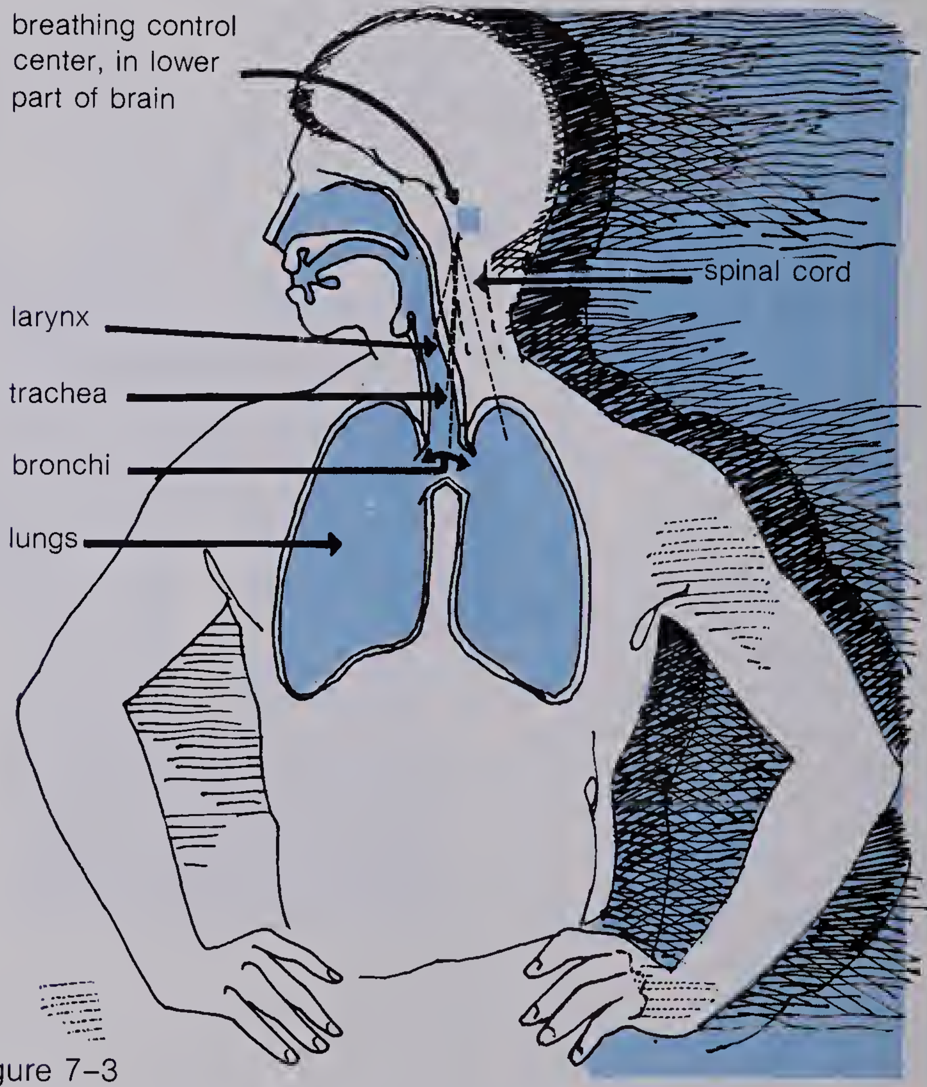


Figure 7–3

Carbon dioxide is in the air you breathe, but it also comes from your body cells as a waste product. When your breathing control center senses more carbon dioxide than normal in the blood, the center speeds up breathing. The increased breathing rate gets rid of the extra carbon dioxide. In this way your breathing system controls itself. Scientists call this kind of self-control *feedback control.*

This may be the first time you've run into feedback control. If so, don't worry if the meaning isn't completely clear. You'll study feedback control in other minicourses. If you've already run into this type of control and still feel uneasy about it, you may want to read *Resource Unit 13*.

Figure 7–4 shows how your breathing control center reacts to feedback. It works to keep the amount of carbon dioxide in your blood constant. Whenever the amount of carbon dioxide (CO_2) changes, the breathing control center responds and adjusts your breathing rate. You can see that the center never rests. It constantly controls the amount of CO_2 in the blood by constantly controlling the breathing rate, whether you're exercising or sleeping.

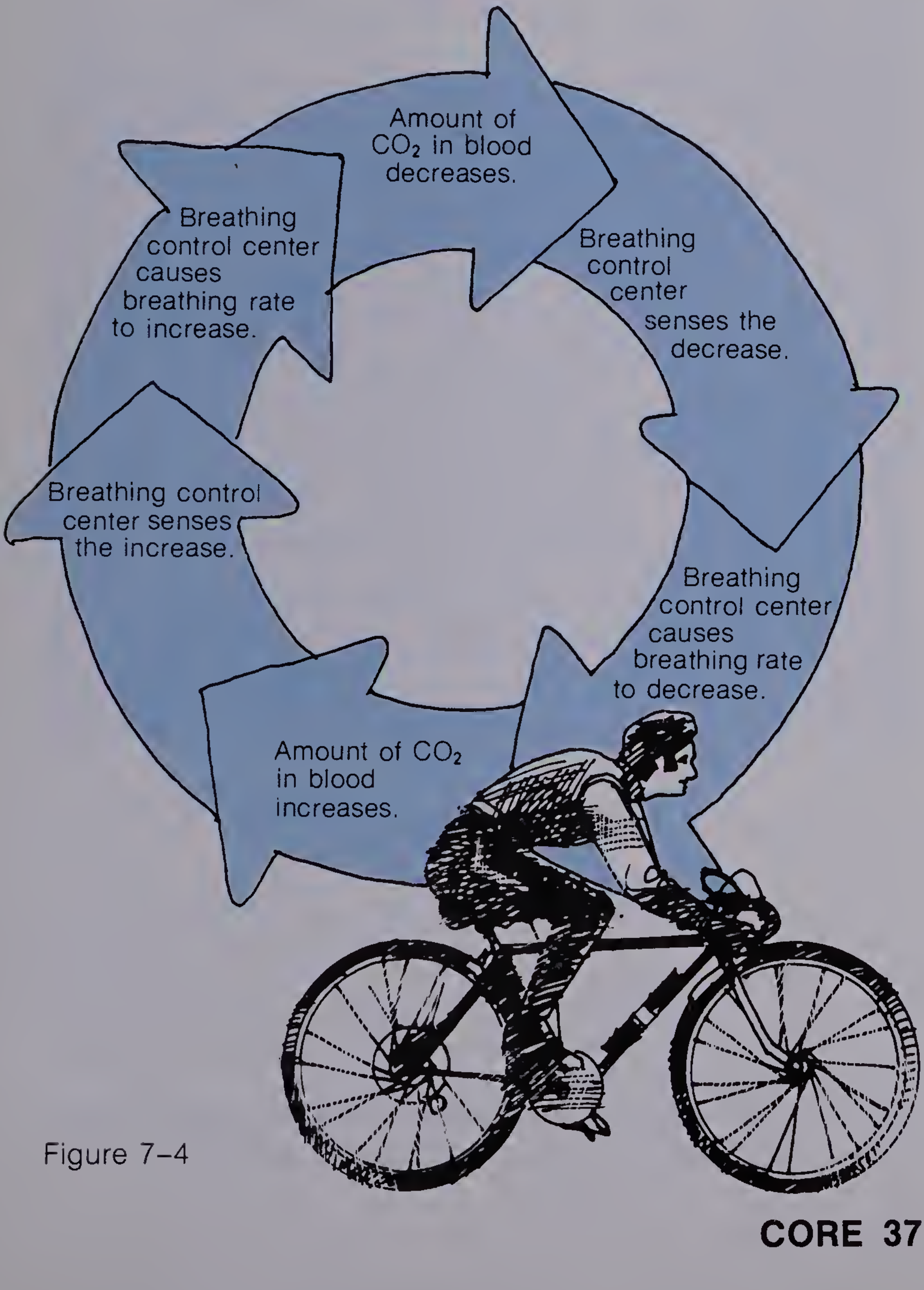

Amount of CO_2 in blood decreases.
Breathing control center senses the decrease.
Breathing control center causes breathing rate to decrease.
Amount of CO_2 in blood increases.
Breathing control center senses the increase.
Breathing control center causes breathing rate to increase.

Figure 7–4

★ 7–10. When you breathe fast, you lower the amount of carbon dioxide in your blood. Your breathing control center senses this decrease. Predict what will happen next.

7-10. The breathing control center will slow down the breathing rate. (Less CO_2 is then expelled and the CO_2 level in the blood increases.)

Caution students against hyperventilating indiscriminately. And for their own sake, if they're going to do it, another person should be present.

Some swimmers and divers use a special breathing technique to stay underwater longer. The technique is called *hyperventilation* [high-per-vent-il-AY-shun] and it makes use of the breathing control system. To hyperventilate, several deep, quick breaths are taken. This brings in extra oxygen and greatly reduces the amount of carbon dioxide in the blood.

✓ 7–11. A swimmer who has hyperventilated may not feel a strong urge to breathe for several minutes. Why?

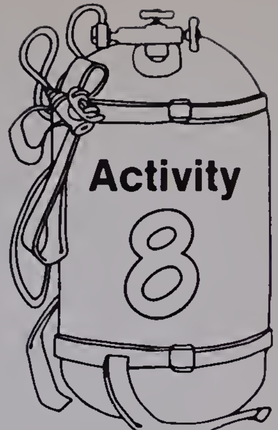
7-11. Hyperventilation decreases the amount of CO_2 in the blood. The breathing control center senses the decrease and reduces the involuntary need to breathe.

Scientists have found that excess hyperventilation can "fool" the breathing control system. When swimmers hyperventilate too much, they don't feel a strong urge to breathe after the usual few minutes. So they use up their supply of oxygen and faint. When they faint, they breathe, and when they breathe, they drown.

★ 7–12. In terms of the feedback control system, why is hyperventilating before going underwater dangerous?

7-12. Hyperventilating lowers the CO_2 level in the blood. This delays triggering the feedback control of the involuntary breathing rate. A swimmer could use up his or her oxygen supply, faint, then breathe unconsciously and drown.

Getting to Your Cells and Back



Every cell in your body must receive oxygen to stay alive. And every cell in your body must unload its waste carbon dioxide. Those two needs are met through the combined actions of the alveoli, the blood, and the body cells themselves.

To see how oxygen and carbon dioxide move to and from the body's cells, you will need a cassette player and the tape for *Getting Enough Oxygen.* Follow the pictures on pages 40 and 41 as you listen to the band for Activity 8. You may want to stop the tape to study the diagrams. When you're done, you should be able to answer Questions 8–1 through 8–4. If you want more information on diffusion, see *Resource Unit 12.*

ACTIVITY EMPHASIS: The roles played by alveoli, red blood cells, and blood plasma in moving oxygen and carbon dioxide into and out of body cells.

MATERIALS PER STUDENT UNIT

cassette tape for *Getting Enough Oxygen*

cassette player, preferably with headphones

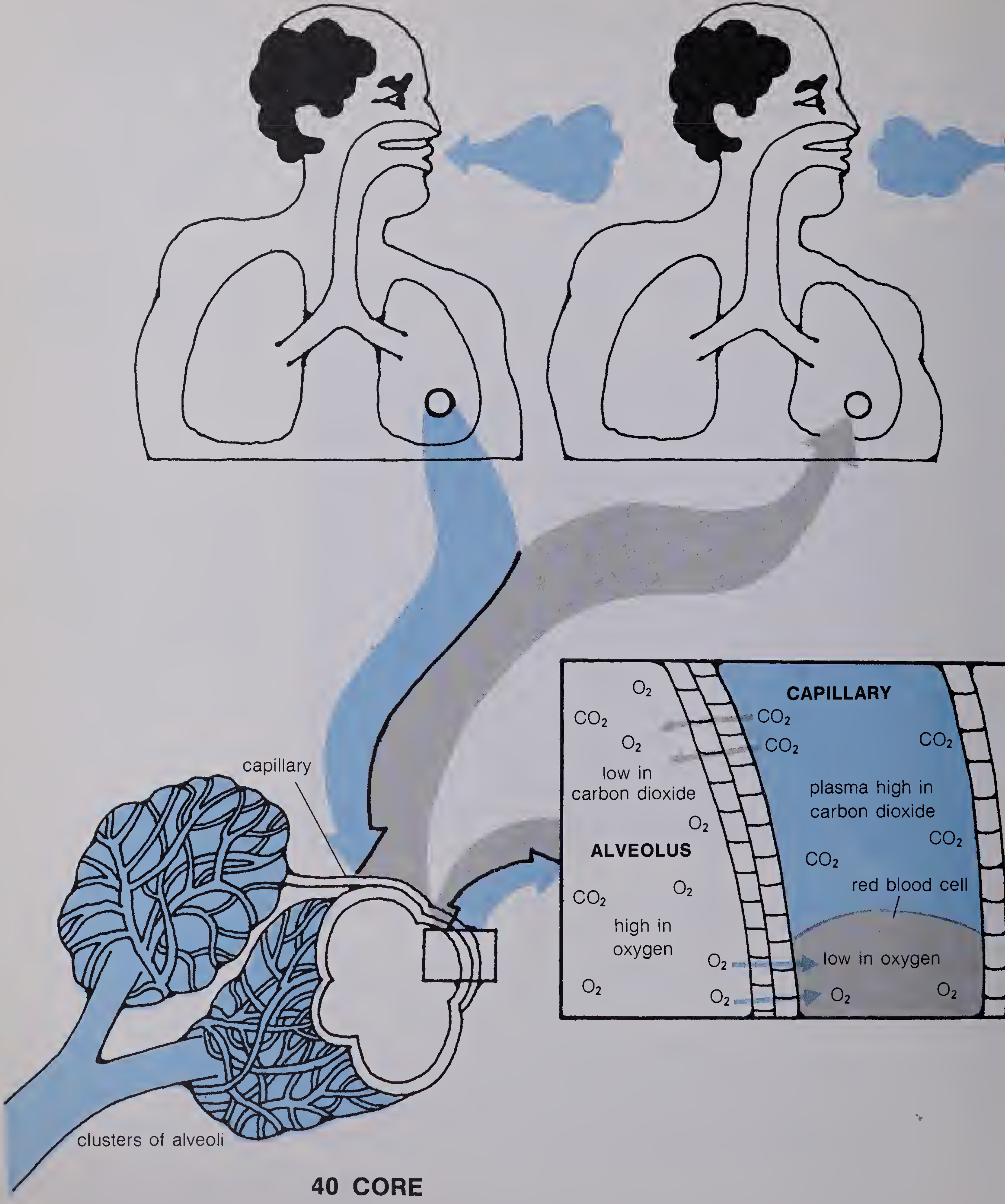
Resource Unit 12

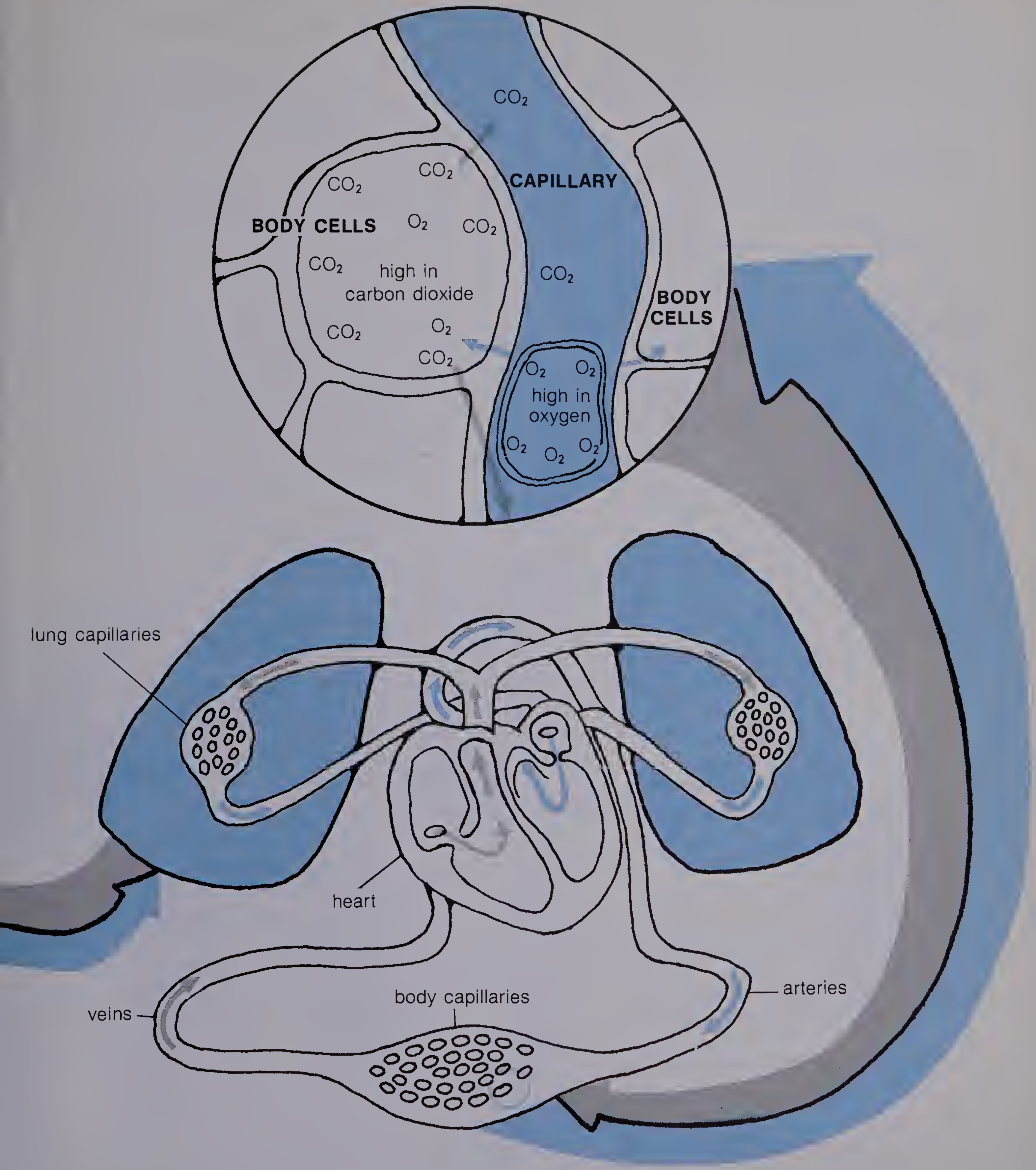
★ **8–1. In what structures are carbon dioxide and oxygen exchanged in the lungs?** 8-1. The alveoli.

★ **8–2. What kinds of cells carry oxygen from the lungs to the body cells?** 8-2. Red blood cells.

★ **8–3. What substances carry carbon dioxide from the body cells to the lungs?** 8-3. Blood plasma (with the CO_2 in the form of bicarbonate ions) and red blood cells.

★ **8–4. What kinds of cells use up oxygen and produce carbon dioxide as waste?** 8-4. Body cells.


capillary
clusters of alveoli
ALVEOLUS
O_2
CO_2
O_2
low in carbon dioxide
O_2
CO_2
O_2
high in oxygen
O_2
O_2
O_2
CAPILLARY
CO_2
CO_2
CO_2
plasma high in carbon dioxide
CO_2
CO_2
red blood cell
low in oxygen
O_2
O_2


CO2
CO2
CO2
CAPILLARY
BODY CELLS
O2
CO2
CO2
high in carbon dioxide
CO2
BODY CELLS
CO2
O2
CO2
O2
O2
high in oxygen
O2
O2
O2
lung capillaries
heart
veins
body capillaries
arteries

advanced

Activity 9 Planning

Activity 10 Page 43

Objective 14: Describe the roles of oxygen, glucose, ATP, mitochondria, enzymes, and the Krebs cycle in cellular respiration.

Sample Question: Match each item in List A with its role in cellular respiration in List B.

List A

a. oxygen
b. glucose
c. ATP
d. mitochondria
e. enzymes
f. Krebs cycle

List B

1. active acetate enters this
2. makes ATP and glucose
3. "stimulates" respiration reactions
4. reacts with hydrogen from "hydrogen pathway"
5. where most respiration reactions occur
6. energy source in food
7. energy-storage molecule in cells

Objective 15: Describe the main steps in the cellular respiration of glucose.

Sample Question: What is the order of these steps in the cellular respiration of glucose?

a. formation of active acetate
b. formation of water
c. Krebs cycle
d. formation of pyruvic acid

Activity 11 Page 50

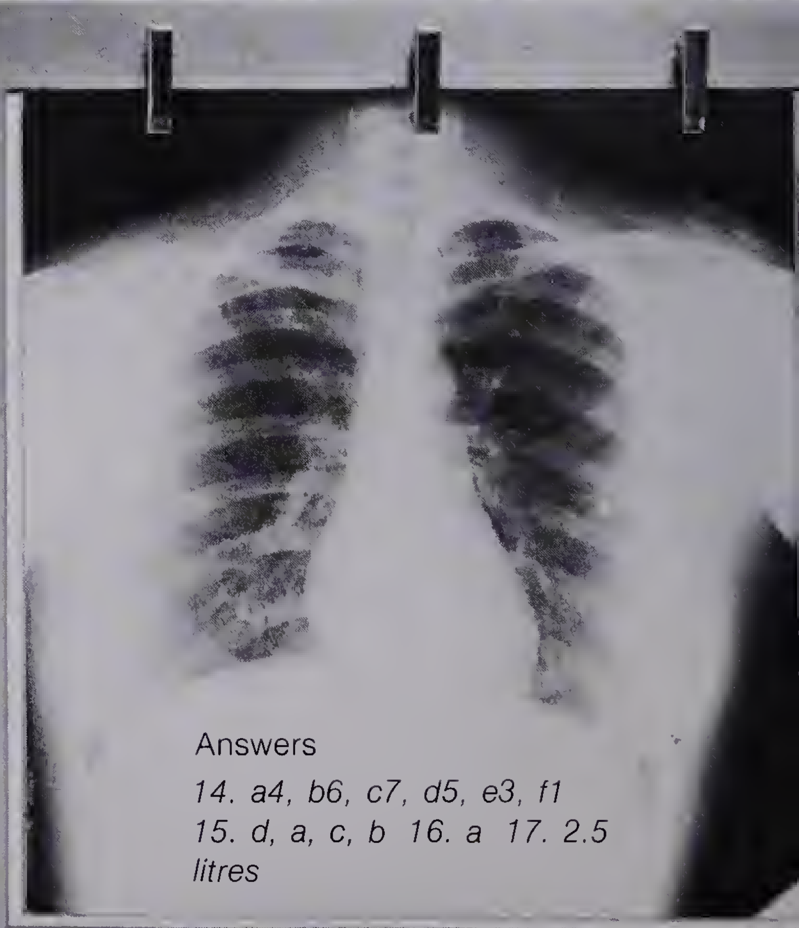
Objective 16: Tell how pressure and volume of a confined gas at constant temperature are related (Boyle's Law).

Sample Question: Assume a constant temperature. If the pressure on a litre sample of air were decreased, the volume would

a. increase.
b. decrease.
c. stay the same.

Objective 17: Solve problems about gas pressure and volume using Boyle's Law.

Sample Question: Suppose the pressure on a 10-litre sample of air were changed from 1 atm to 4 atm at constant temperature. What volume would the air occupy at 4 atm?

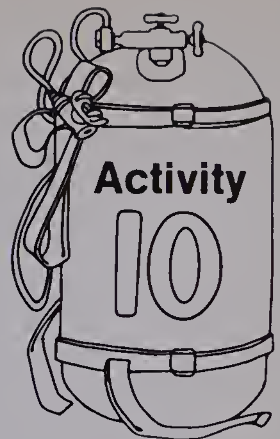


Answers

14. a4, b6, c7, d5, e3, f1
15. d, a, c, b 16. a 17. 2.5 litres

Respiration Revisited

ACTIVITY EMPHASIS: Structures and substances involved in the complicated chemical process of cellular respiration. The controlled release of energy and its storage in chemical bonds.

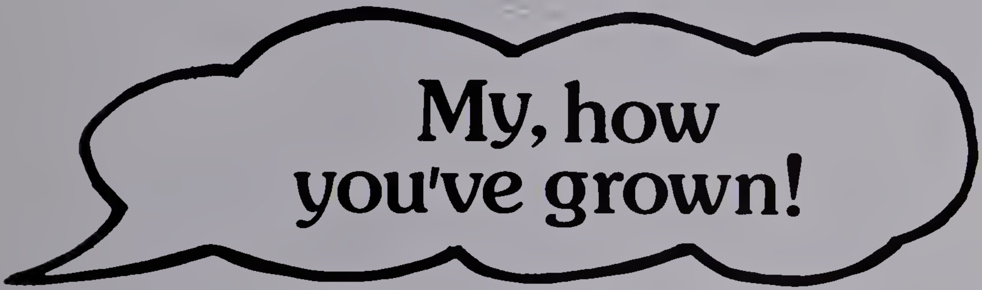


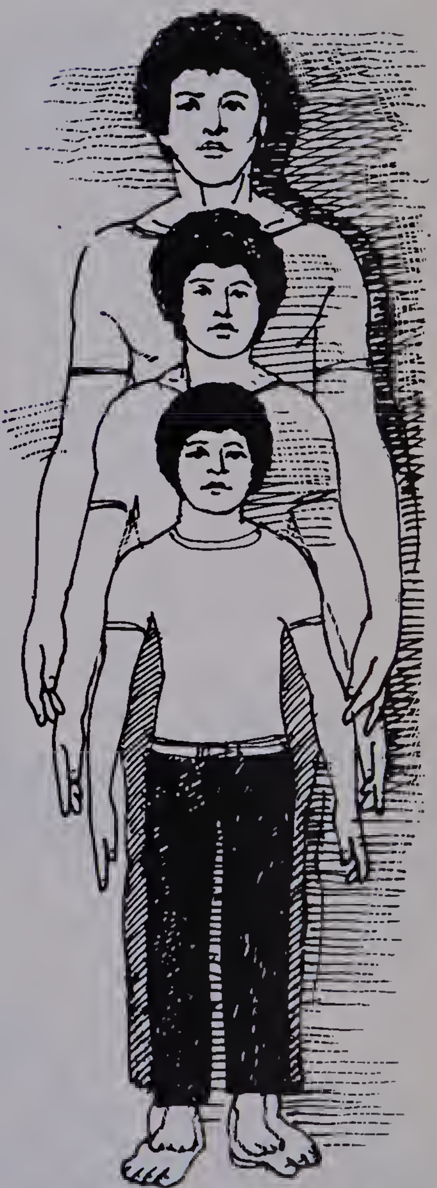
MATERIALS PER STUDENT UNIT

None.

You've grown because your body can take the things you eat — the hamburgers, the spaghetti, the knockwurst, the enchiladas — and break them down into molecules of food that your body cells can use.

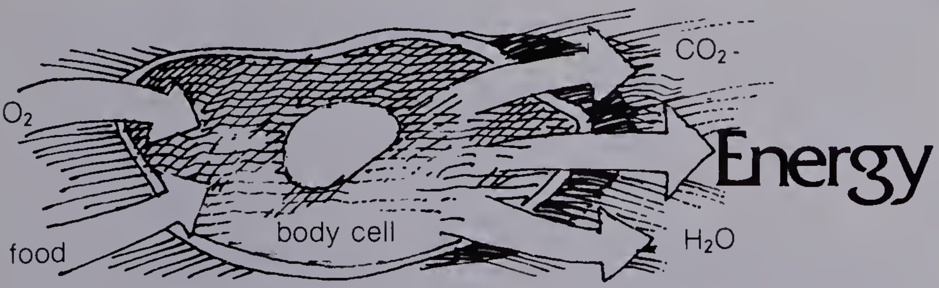
The food molecules that break down from proteins provide the building blocks for new cells. Other food molecules are broken down for energy. The energy is needed to keep your body warm, to make your muscles move, to make new cells, and to run the processes that took the food molecules apart in the first place.


My, how you've grown!



To keep you alive and growing, every living cell in your body must be involved in respiration — the process of getting energy from food molecules. Respiration was described in Activity 5 by this statement:

oxygen + food → carbon dioxide + water + energy



This is a great simplification. The statement doesn't say where the energy comes from, how the energy is released, or where the carbon dioxide (CO_2) and water (H_2O) come from. To better understand what's going on during respiration, you need to know more about food molecules, energy substances, and cells.

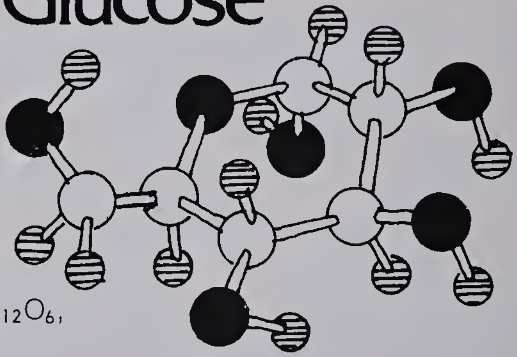
Indirectly, fats and carbohydrates are the main sources of energy for your body. Directly, your body gets most of its energy from the simple sugar glucose, a basic food molecule. Reactions in your body break down carbohydrate molecules into molecules of glucose.

A Model for Glucose

○ carbon atom (C)

▤ hydrogen atom (H)

● oxygen atom (O)



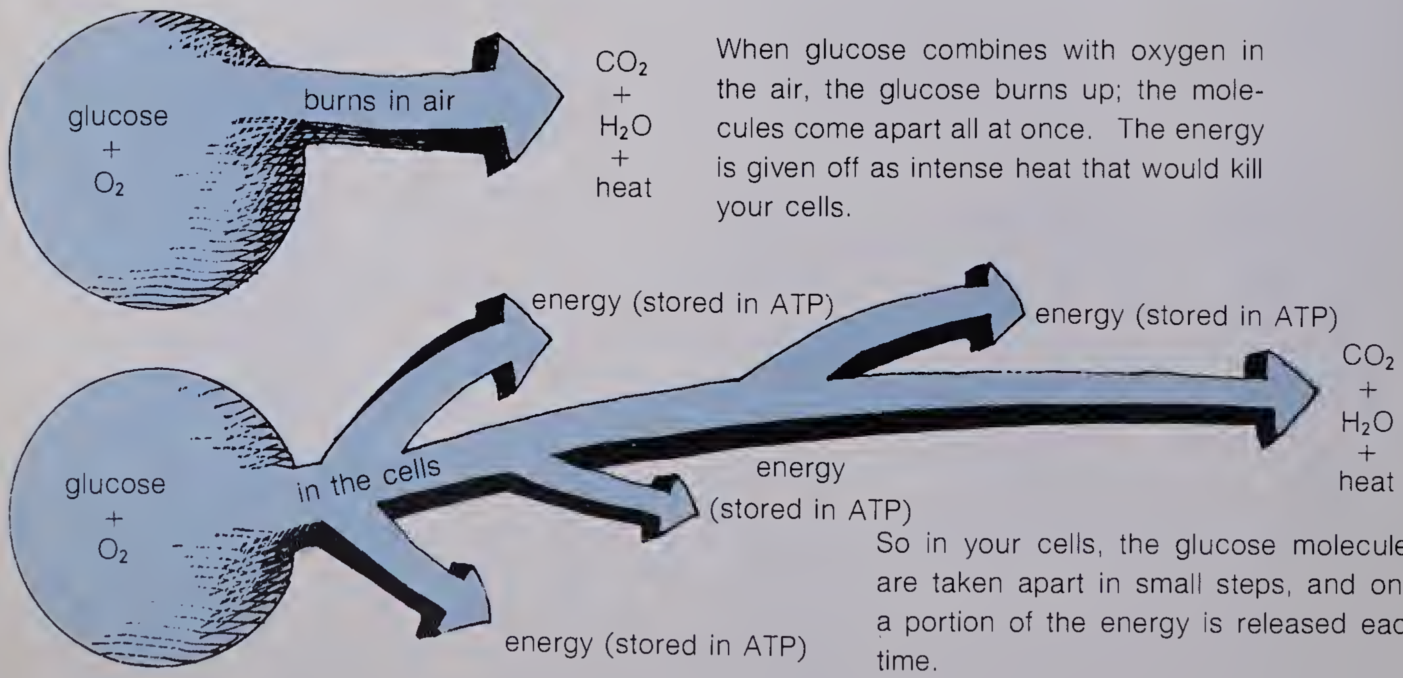
Count them up and you get $C_6H_{12}O_6$, or one molecule of glucose.

Glucose molecules contain a lot of stored energy. When a molecule of glucose comes apart, its stored energy is released. When oxygen is present, carbon dioxide and water molecules are formed. The chemical equation for this reaction is —

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

glucose + oxygen → carbon dioxide + water + energy

You can see in this equation that one molecule of glucose needs six molecules of oxygen for the reaction to take place.



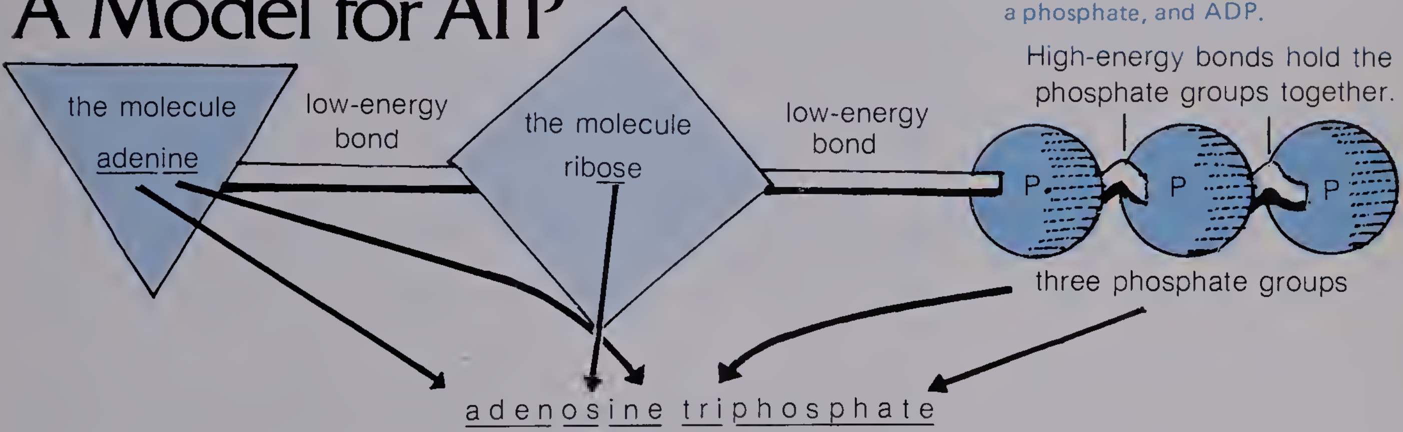
When glucose combines with oxygen in the air, the glucose burns up; the molecules come apart all at once. The energy is given off as intense heat that would kill your cells.

So in your cells, the glucose molecules are taken apart in small steps, and only a portion of the energy is released each time.

As the energy is released, only about half of it is lost as heat; the other half is stored for future use. Energy is stored by the cells in large, complicated molecules called *ATP* (adenosine triphosphate). The individual atoms that make up the ATP molecule are held together by bonds, two of which are called *high-energy bonds.* The energy released during the breakdown of glucose is stored in ATP's high-energy bonds.

For simplicity, the involvement of ADP (adenosine diphosphate) is not discussed here. Interested students may like to know that ATP actually results from a combination of ADP, a third phosphate, and energy (ADP + P + energy → ATP). Where ADP has only one high-energy bond, ATP contains two. When an ATP molecule's stored energy is needed by the body, one of the bonds breaks, and the result is released energy, a phosphate, and ADP.

A Model for ATP



10–1. You have read that only about half of the energy released by the glucose is "lost as heat." The heat "lost" does serve a useful function, however. What do you think that is?

10-1. It helps keep the body temperature constant, warm enough to carry on life-sustaining reactions.

The cells in your body contain many structures and substances. Each structure and substance has a special function. The respiration process occurs in structures called *mitochondria* [might-a-KON-dree-a]. They are often referred to as the "powerhouses" of the cell, for it is inside the mitochondria that ATP molecules are formed and oxygen is used. A mitochondrion is shown in Figure 10–1.

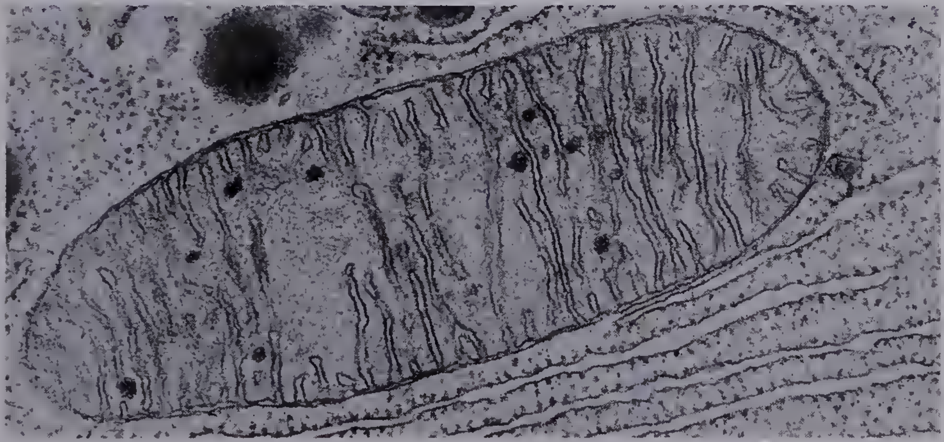
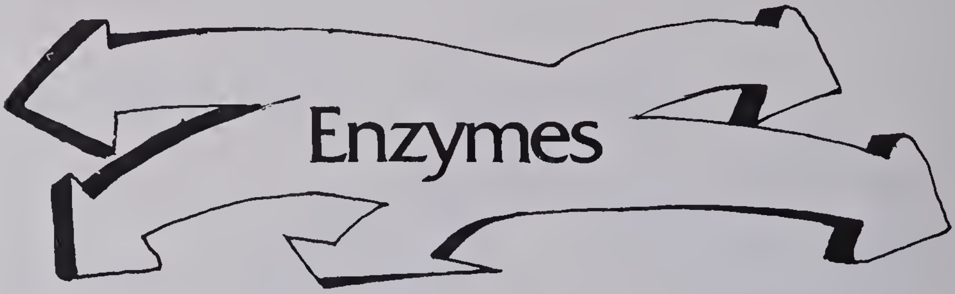


Figure 10–1

Certain substances in the cell are also vital to respiration. Mitochondria are where the action is, but there would be no action without *enzymes*. Enzymes are special molecules that make possible most of the reactions that go on in your cells.



You might say that enzymes "stimulate" reactions, and they do it specifically. For instance, an enzyme that stimulates a breakdown of glucose would do nothing for a molecule of protein. Without enzymes, some reactions would never take place and others would occur too slowly to be of any use.

10-2. ATP – molecules that store, for future use, energy produced by respiration. Mitochondria – cell structures in which respiration occurs and ATP molecules are formed. Enzymes – molecules that stimulate all reactions necessary for respiration.

★ **10–2. Describe the roles of ATP, mitochondria, and enzymes in cellular respiration.**

You have enough information now to follow a more detailed analysis of the process of cellular respiration. The first step occurs outside the mitochondria. Steps 2 through 5 occur inside the mitochondria.

Pyruvic acid is also known as *pyruvate.* Active acetate is more technically called *acetyl coenzyme A.* Interested students who decide to go beyond this activity might be introduced to these other terms.

The first step is shown in Figure 10–2. Enzymes, with the help of 2 ATP molecules, cause one molecule of glucose to split in two. Where the glucose molecule contained 6 carbon atoms, each of the two new molecules, called *pyruvic acid,* contains 3 carbon atoms. Enough energy is released when this happens to form 4 ATP molecules. Notice that carbon dioxide and water are not produced during this step.

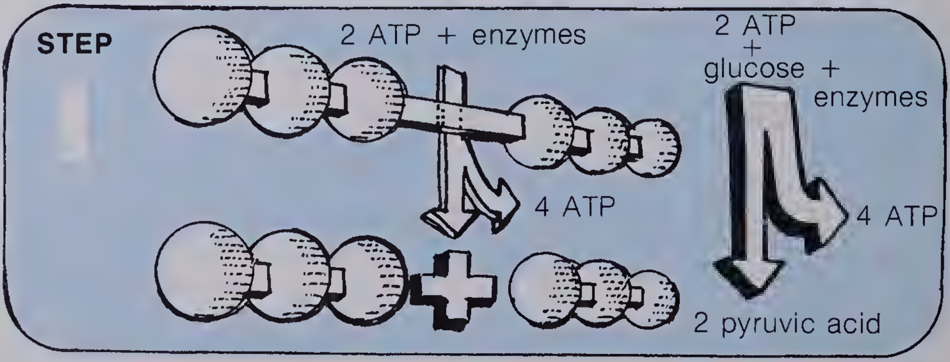


Figure 10–2

In Step 2, now inside the mitochondria, a new set of enzymes breaks down each 3-carbon molecule of pyruvic acid. The result is a 1-carbon molecule (carbon dioxide) and a 2-carbon molecule called *active acetate*. No ATP is made during this step.

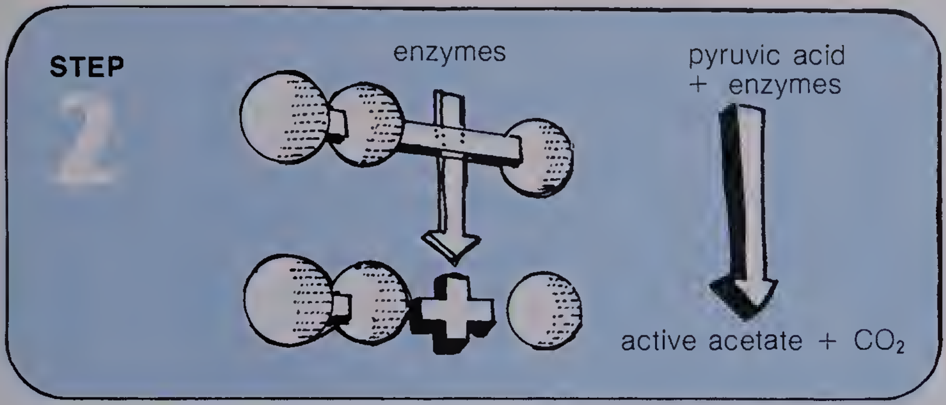


Figure 10–3

✓ 10–3. Taking one molecule of glucose to the stage where active acetate is formed, how many ATP molecules have been formed? How many CO_2 molecules? (Hint: Remember that *two* molecules of pyruvic acid are involved.)

10-3. Four ATP molecules; two CO_2 molecules.

The 2-carbon active acetate molecule immediately enters into the main "disassembly line" known as the *Krebs cycle* (Figure 10–4). Here, in a series of reactions, the 2-carbon molecule is broken down into two 1-carbon molecules.

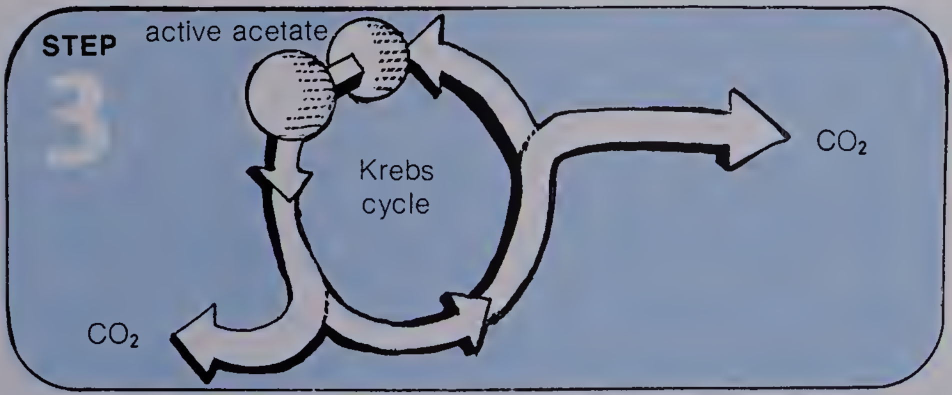


Figure 10–4

Sir Hans Krebs, a British biochemist, first figured out this process. "Cycle" means that the series of reactions is continuous and self-sufficient — that is, the substances involved in the breakdown of active acetate are not used up in the process. As long as active acetate is present, the Krebs cycle will break it down.

✓ 10–4. How many CO_2 molecules are generated from each turn of the Krebs cycle? 10-4. Two CO_2 molecules.

✓ 10–5. Breaking down one molecule of glucose to the stage where the Krebs cycle has turned for each active acetate molecule, how many CO_2 molecules have been formed? 10-5. Six CO_2 molecules.

During the breakdown of glucose and during the Krebs cycle, hydrogen atoms have also been released (Figure 10–5).

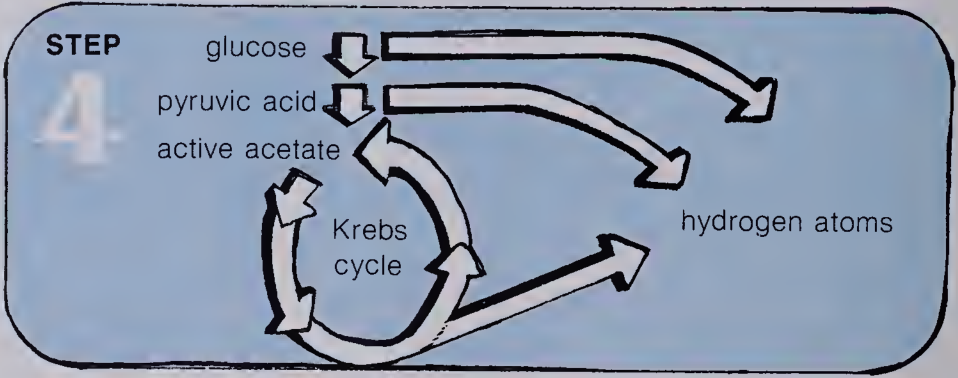


Figure 10–5

The oxygen (O_2) and water (H_2O) that you saw in the equation for respiration can now be accounted for. The oxygen available in the cells can now combine with hydrogen to release energy and produce water. But if the oxygen-hydrogen reaction occurred directly, a flood of energy would be released all at once and wasted. Instead, the flood is controlled in a "hydrogen pathway" (Figure 10–6). A set of enzymes takes the energy from the hydrogen atoms and transfers some of it to ATP molecules while water molecules are formed.

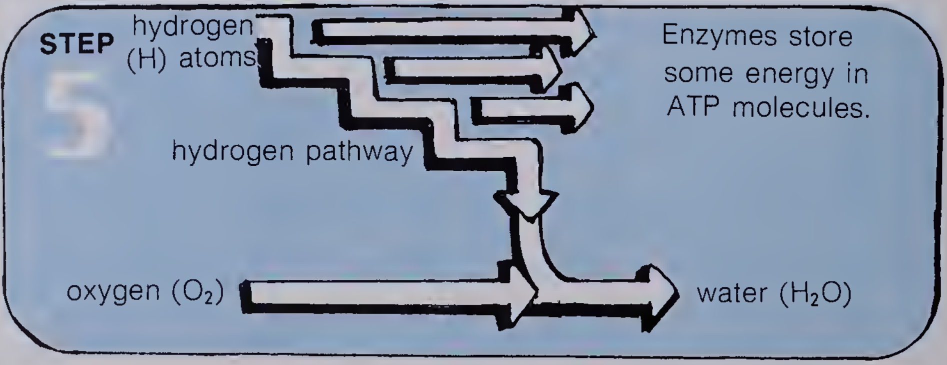
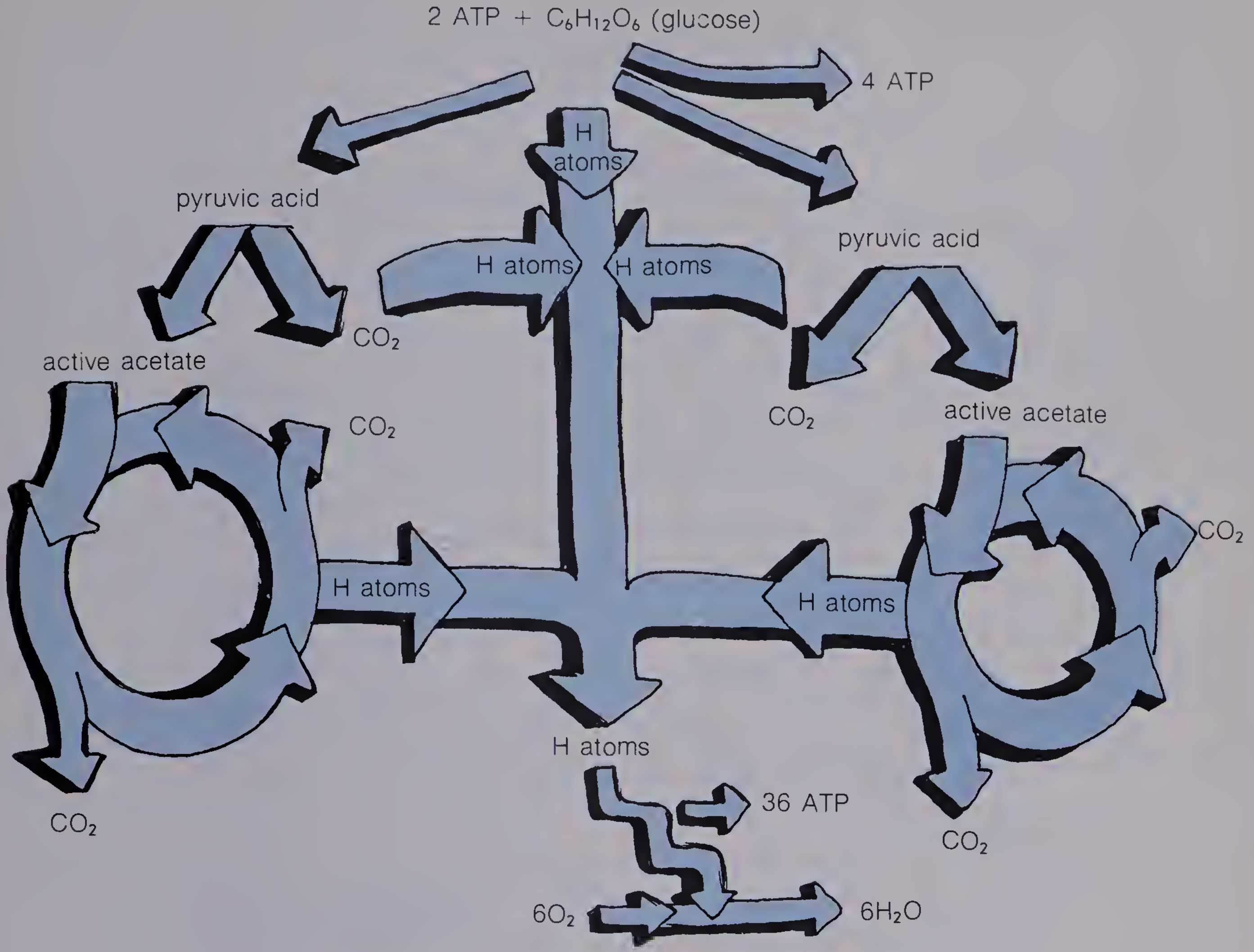


Figure 10–6

★ **10–6. Describe the roles of glucose, the Krebs cycle, and oxygen in cellular respiration.**

10-6. Glucose — raw material from which energy is eventually derived. Krebs cycle — converts active acetate (derived from glucose) to CO_2 molecules and H atoms. Oxygen — combines with H atoms to form water.

The five basic steps in cellular respiration are put together in Figure 10–7. Follow the breakdown of one molecule of glucose.



$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \textbf{energy}$$

Figure 10–7

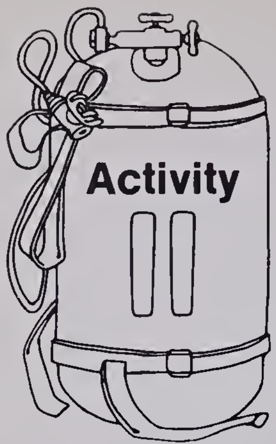
✓ 10–7. Two ATP molecules are required to start respiration. How many are produced? What is the net gain in ATP?

10-7. Forty ATP molecules are produced (four in Step 1, 36 in Step 5). Net gain is 38 ATP molecules (two outside the mitochondrion, 36 inside).

★ **10–8. Use Figure 10–7 to outline in writing the main steps in the cellular respiration of glucose.**

10-8. Enzymes and ATP break down glucose into pyruvic acid, also producing H atoms and ATP. An enzyme breaks down pyruvic acid into active acetate, also producing H atoms and CO_2. Active acetate enters the Krebs cycle; H atoms and CO_2 are produced. In the hydrogen pathway, enzymes cause energy from the H atoms to be stored in ATP. Enzymes cause oxygen in the cell to combine with hydrogen to form water.

The total process of respiration includes a tremendous number of chemical reactions. Each reaction is controlled by a separate enzyme or set of enzymes. Compared to the energy lost when glucose burns, respiration is a very efficient process, since it puts about 50% of glucose's valuable energy into ATP molecules. Stored in ATP, the energy is available for such activities as muscle flexing, cell maintenance, and body growth.



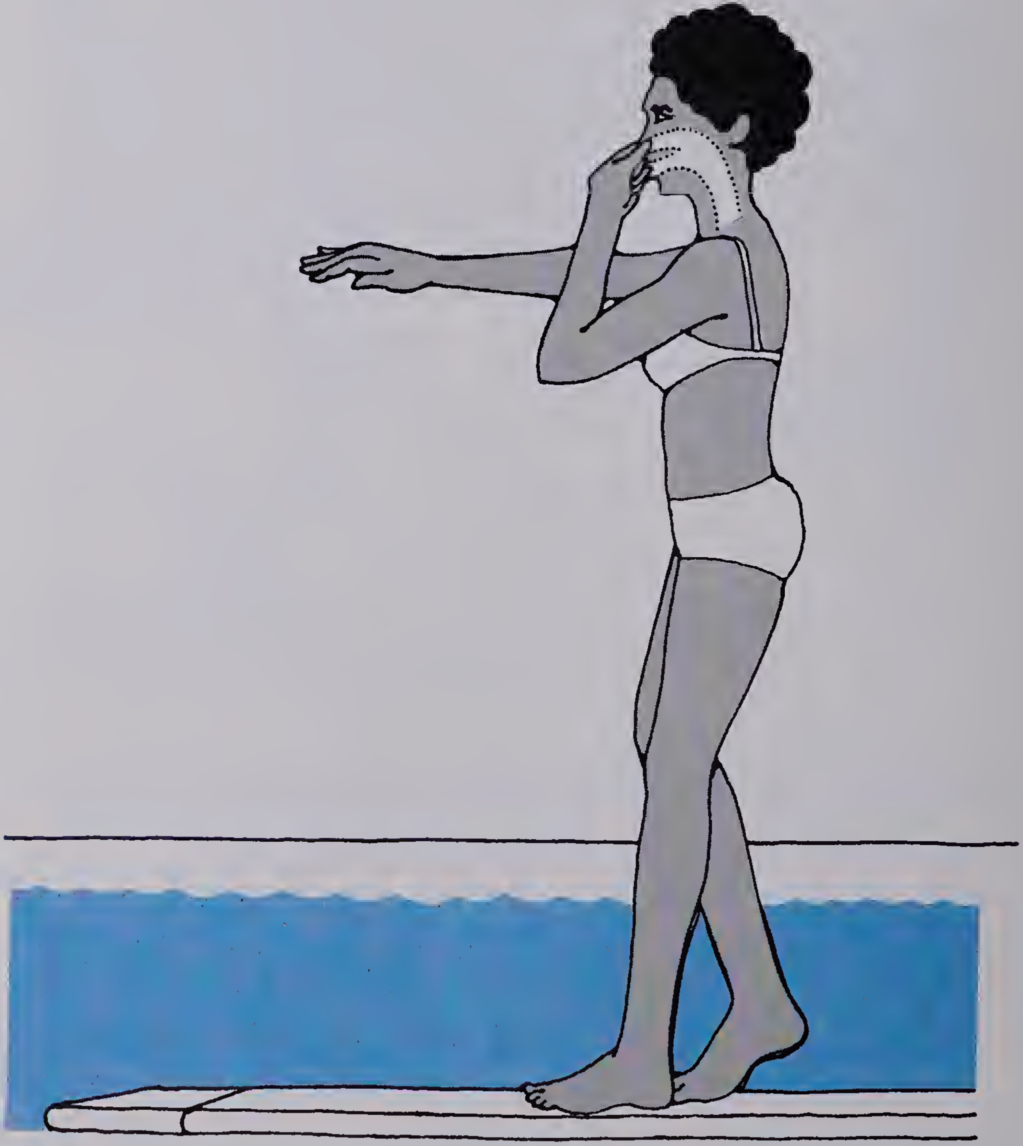
Pressure and Volume

ACTIVITY EMPHASIS: Pressure and volume at constant temperature are inversely proportional for a fixed mass of gas (Boyle's Law). This relationship is applied to underwater activities.

MATERIALS PER STUDENT UNIT

pressure-volume apparatus (see also Advance Preparation, p. TM 9)
weights, such as bricks or large books, 4-6 of equal mass
Resource Units 4, 5, and 6

Under normal conditions, your breathing system is open to the outside air. But sometimes you close the system — when you swim or dive, for instance. When the system is closed, there is a certain relationship between the pressure of the air in your lungs and the volume the air occupies.

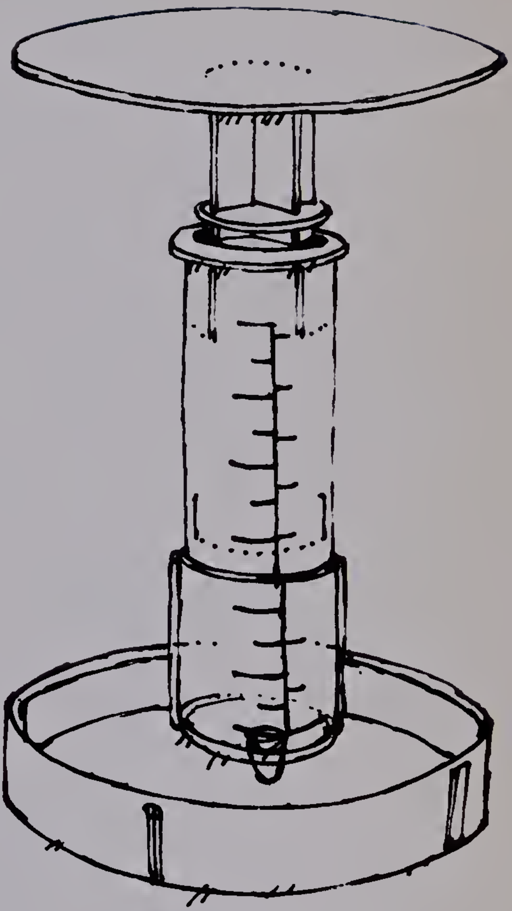


The relationship between the volume and pressure of a gas was first discovered over 300 years ago by the English chemist Robert Boyle.

Using a simple setup, you can also discover the relationship. You will need the following:

See Advance Preparation, p. TM 9, for details on assembling your own pressure-volume apparatus.

- pressure-volume apparatus labeled
  Getting Enough Oxygen, Activity 11
- 4–6 weights, such as bricks or large books



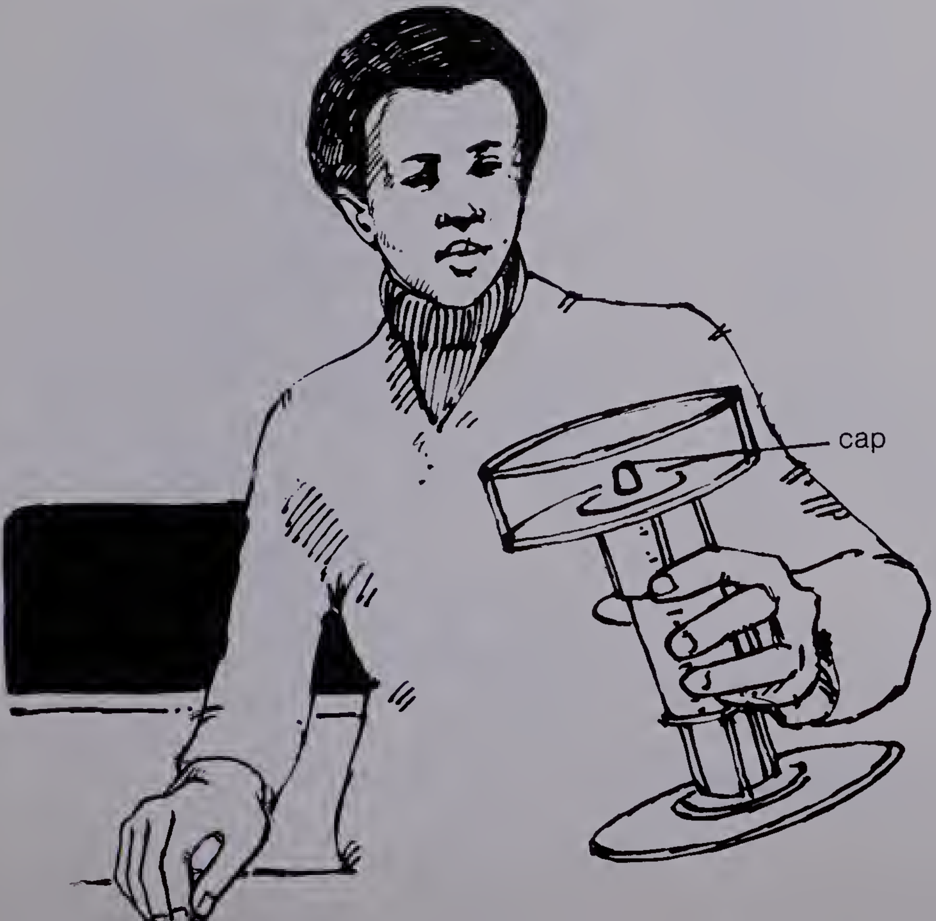
PRESSURE AND VOLUME

NO. OF WEIGHTS	VOLUME OF AIR			AVERAGE VOLUME (V_{avg})	INVERSE OF VOLUME ($1/V_{avg}$)
	Trial 1	Trial 2	Trial 3		
1					
2					
3					
4					

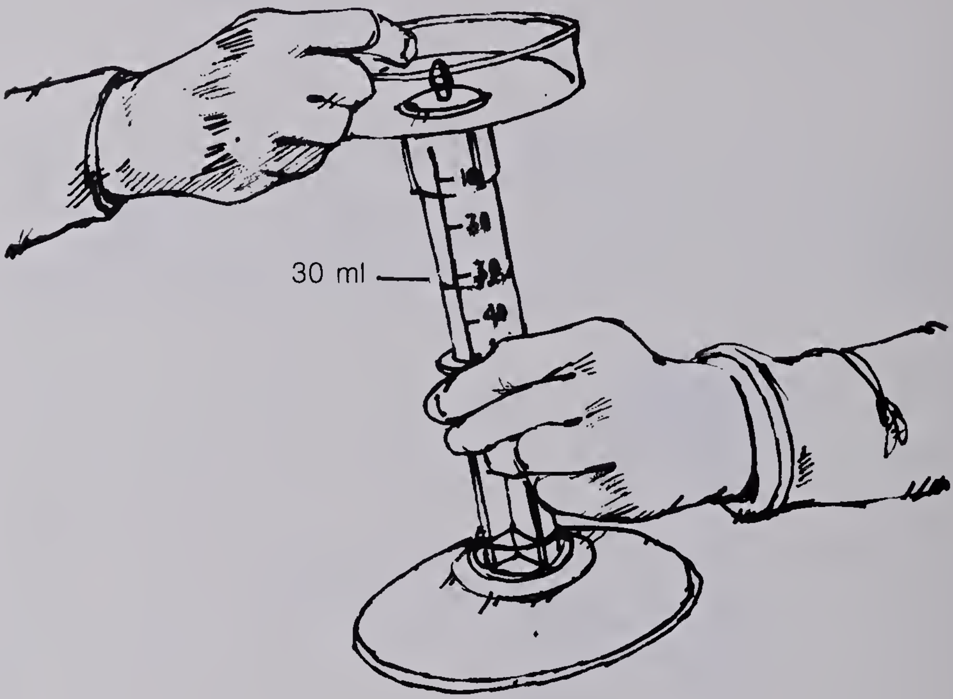
Figure 11–1

Before you start, draw a table similar to Figure 11–1 in your notebook. Use it to record your data during the investigation.

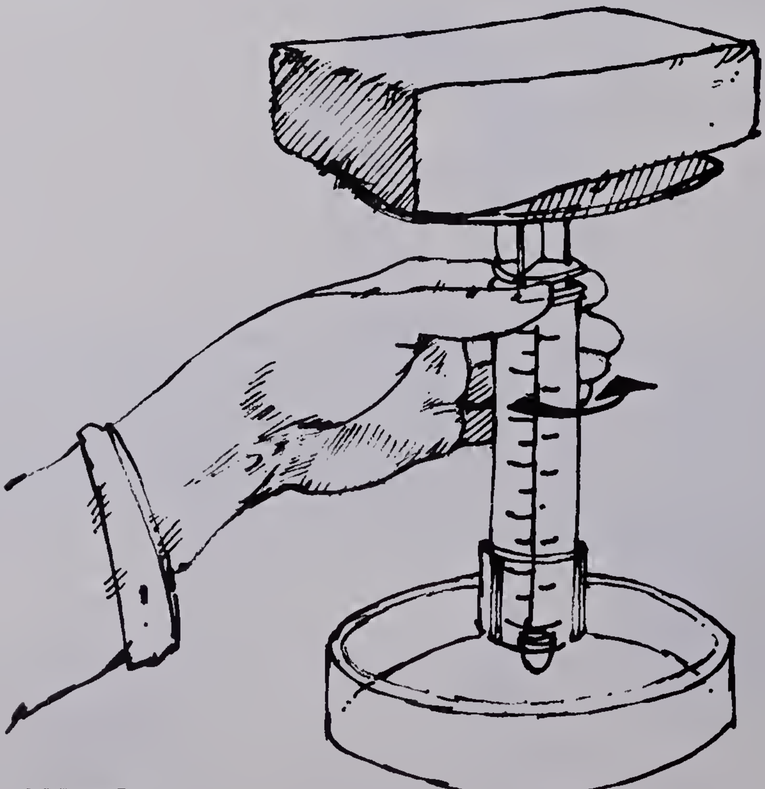
A. Check that the air piston has a cap.



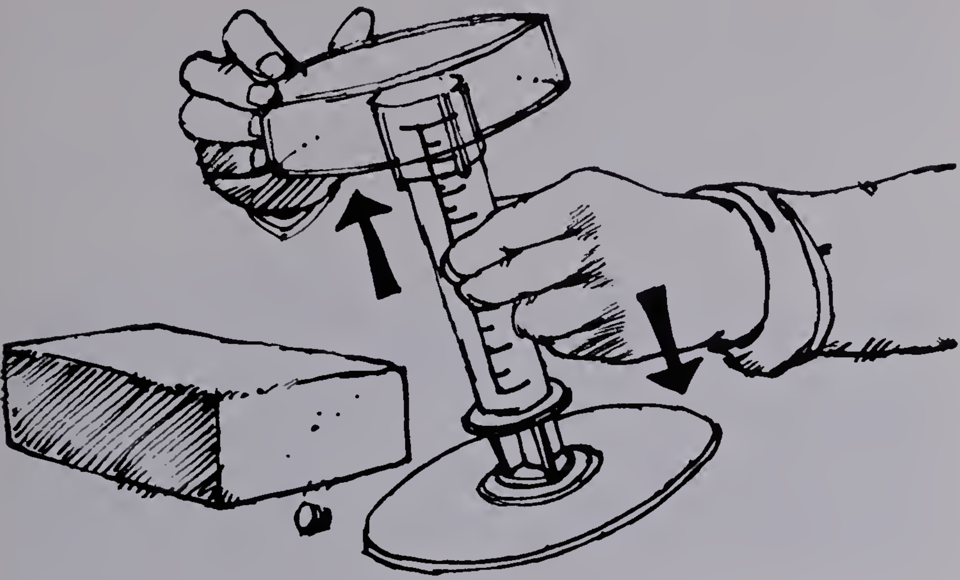
B. Remove the cap from the air piston. Insert the plunger into the piston. Adjust the volume of air in the piston to 30 ml. Replace the cap.



C. Set one weight, such as a brick or large book, on the platform. Twist the plunger a bit in case it is sticking. Read the volume of air in the piston. Record your reading under "Trial 1" for one weight.



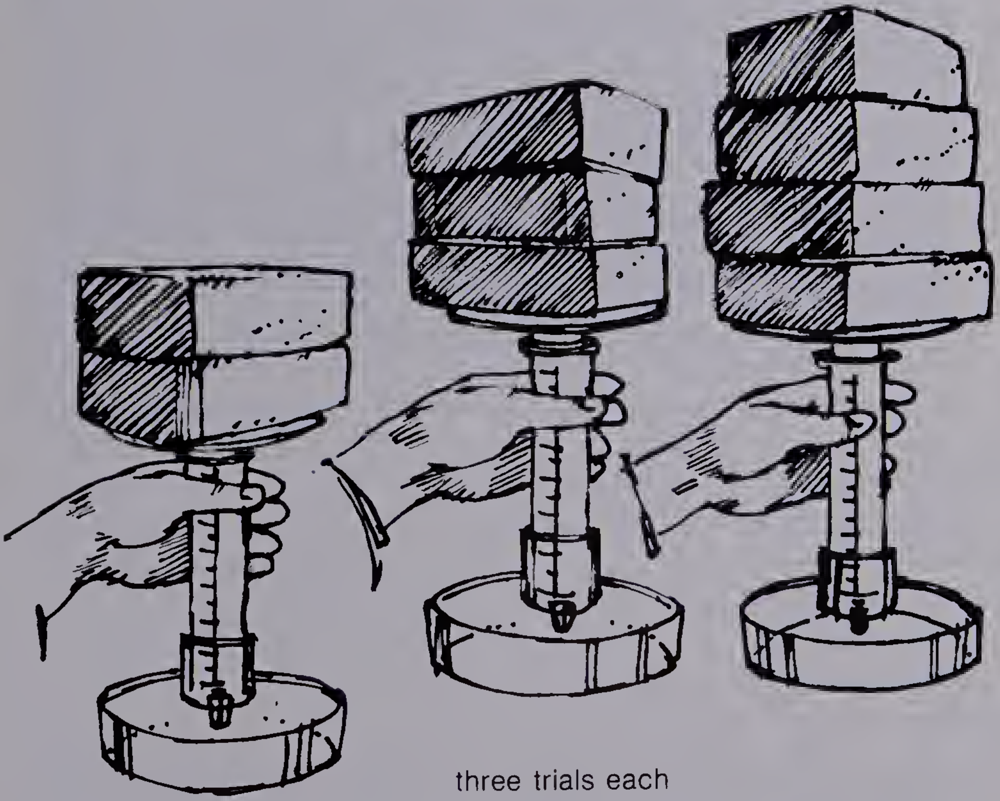
D. Remove the weight. Then remove the cap and pull out the plunger. Repeat Steps B and C for Trial 2 and for Trial 3.



✓ 11–1. Why is it a good idea to do several trials with the same number of weights?

11-1. To notice any mistakes, to average out variations, to be more sure of the results.

E. Repeat the procedure for 2, 3, and 4 weights, doing three trials each time. Record your data after each trial.



three trials each

Each time you added a weight to the plunger, you increased the pressure on the gas inside the piston.

★ **11–2. As you increase pressure, what happens to the volume of air trapped inside a container?** 11-2. Volume decreases.

See if you can find a mathematical relationship between pressure and volume. The following questions will help you.

Have *Resource Unit 4* available to aid students in graphing.

✓ 11–3. Using your data from the trials, calculate the average volume (V_{avg}) produced by each number of weights. Enter the results in your table. 11-3. Results will vary.

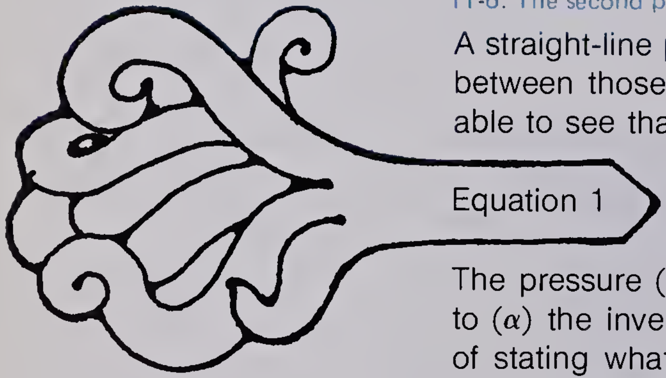
✓ 11–4. Calculate the inverse of the average volume ($1/V_{avg}$) for each number of weights. Enter the results in your table.
11-4. Results will vary.

11-5. Graph plots will vary, but the second plot should be more nearly straight.

✓ 11–5. Make two graphs of your data. On one grid, plot the number of weights against their V_{avg} values. On a second grid, plot the number of weights against their $1/V_{avg}$ values. (If you need help making these graphs, refer to *Resource Unit 4*.)

✓ 11–6. Of the two graphs you made for Question 11–5, which plot is more nearly a straight line? (A ruler may help.)
11-6. The second plot.

A straight-line plot for two variables indicates a direct relationship between those variables. From your data, then, you should be able to see that —

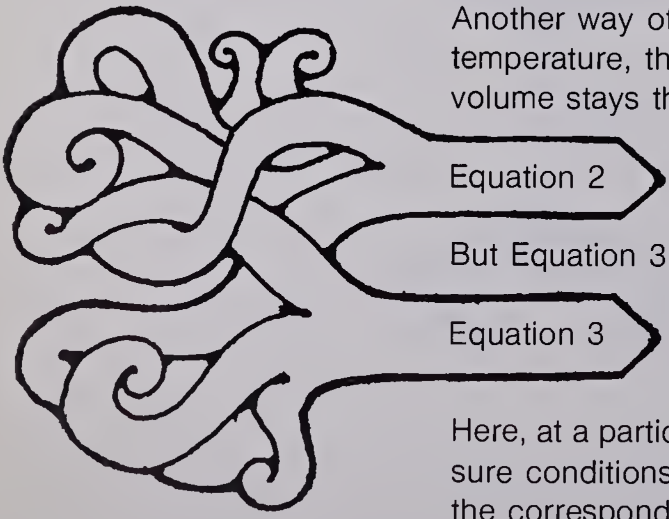


Equation 1 $P \alpha \frac{1}{V}$

Robert Boyle (1627–1691) is sometimes called the father of modern chemistry. This English chemist and physicist was the first to experiment with what he termed "the springiness of air."

The pressure (P, the number of weights) is directly proportional to (α) the inverse of the volume ($1/V$). Equation 1 is one way of stating what is now known as *Boyle's Law*, which holds for any confined gas at a constant temperature.

Another way of stating Boyle's Law is to say that at a particular temperature, the product of the pressure and the corresponding volume stays the same, or —



Equation 2 $PV = \text{constant}$

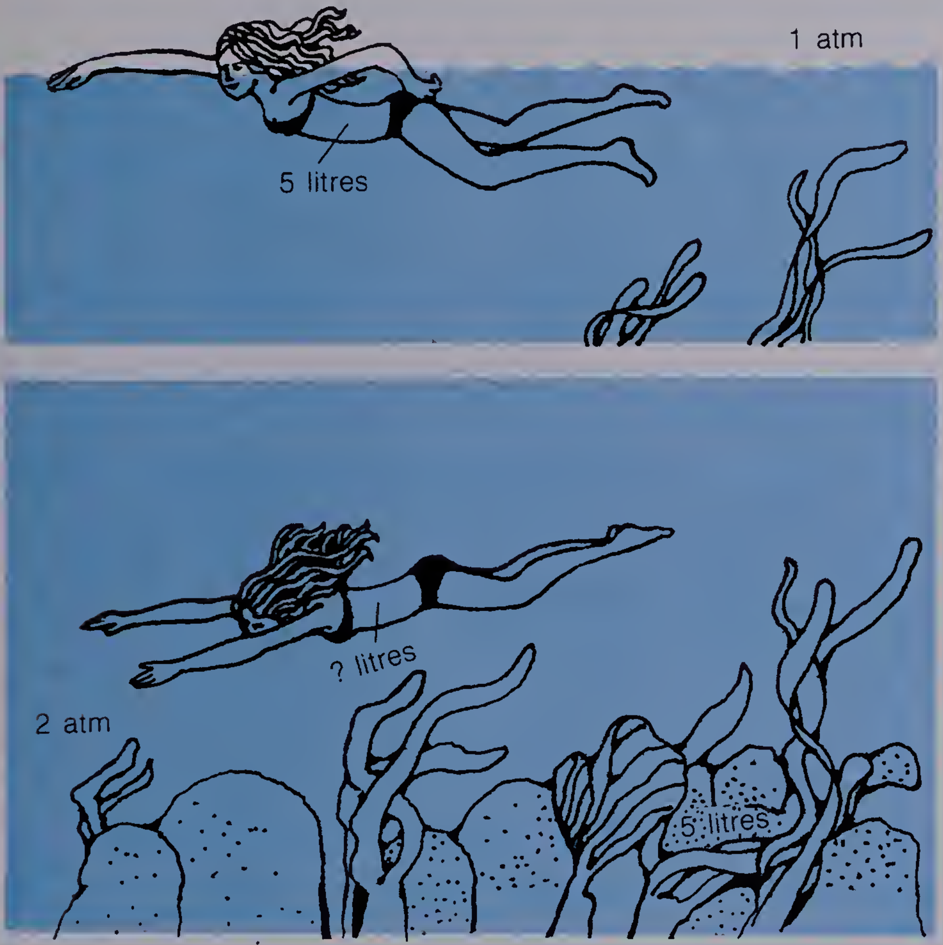
But Equation 3 is the most useful way to state Boyle's Law.

Equation 3 $P_1V_1 = P_2V_2$

Here, at a particular temperature, P_1 and P_2 are two different pressure conditions for the same amount of gas, and V_1 and V_2 are the corresponding volumes at those pressures.

Suppose a swimmer takes a lungful of air at the water surface and dives downward. The increased water pressure will squeeze the air in the lungs into a smaller volume. Any air in the small air spaces in the head (the sinuses) and in the middle ear can also be squeezed by increased water pressure.

The effects of pressure increase can be calculated using Boyle's Law. In the following example, if you're not sure about volume and pressure measurements, refer to *Resource Units 5* and *6*.



Have *Resource Units 5* and *6* available to aid students in understanding measurements of volume and pressure.

Sample Problem: A swimmer takes a 5-litre lungful of air at the water surface and swims down to a depth of 10 metres. The air pressure at the surface was 1 atmosphere (atm). The water pressure at 10 metres is 2 atm. What volume of air is in the swimmer's lungs at 10 metres?

$P_1 = 1$ atm $\quad V_1 = 5$ litres

$P_2 = 2$ atm $\quad V_2 = ?$

$$P_1V_1 = P_2V_2 \quad \text{(Boyle's Law)}$$

$$\frac{P_1V_1}{P_2} = V_2 \quad \text{(Solve for } V_2\text{)}$$

$$2.5 \text{ litres} = V_2$$

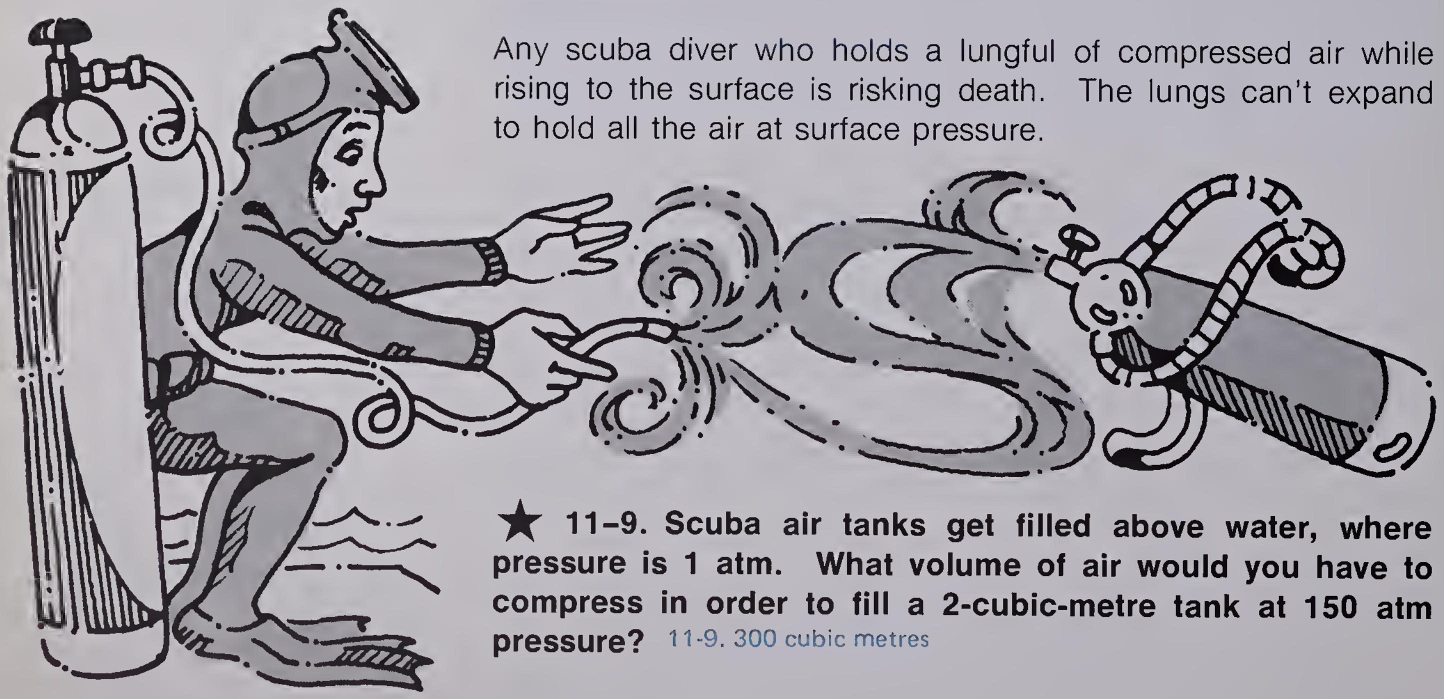
At 10 metres underwater, the volume of air in the swimmer's lungs is only half what it was at the surface. 11-7. 5 litres (same volume as swimmer started with)

✓ 11–7. Suppose the swimmer in the example returned to the surface without letting any air out. What volume of air would be in her lungs at the surface?

You can find the answer to that question inside one of the rocks on page 55. If you got Question 11–7 right, you have grasped the idea of how gas compresses and expands in a confined area. Now try a diving problem on your own.

★ **11–8. A scuba diver inhales 5 litres of air from his air tank while 20 metres underwater. This is where the pressure is 3 atm. Suppose the diver then holds that breath and rises to the surface. What volume of air would be in his lungs at the surface?** 11-8. 15 litres

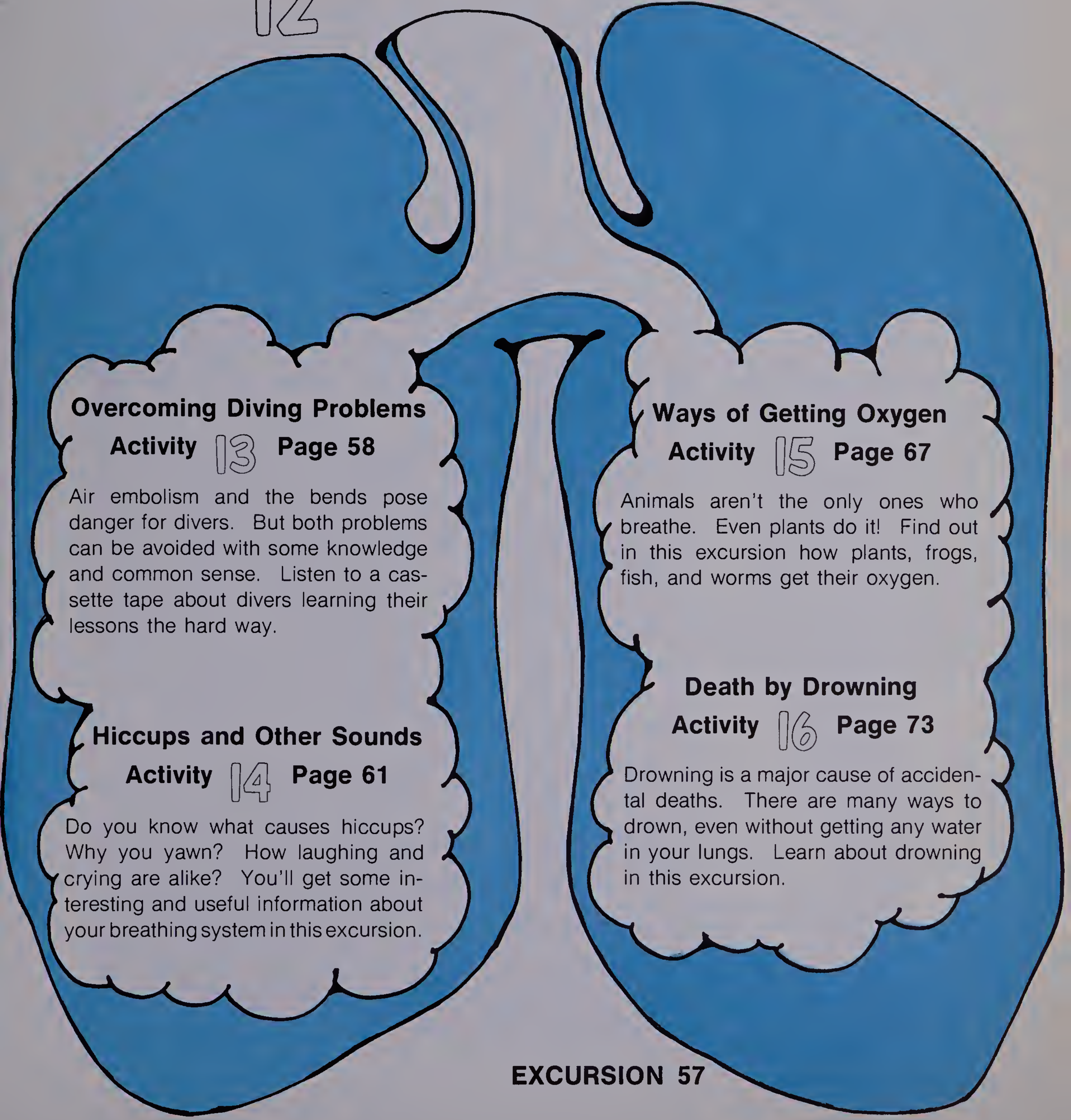
Any scuba diver who holds a lungful of compressed air while rising to the surface is risking death. The lungs can't expand to hold all the air at surface pressure.



★ **11–9. Scuba air tanks get filled above water, where pressure is 1 atm. What volume of air would you have to compress in order to fill a 2-cubic-metre tank at 150 atm pressure?** 11-9. 300 cubic metres

excursion

Activity 12 Planning



Overcoming Diving Problems

Activity 13 Page 58

Air embolism and the bends pose danger for divers. But both problems can be avoided with some knowledge and common sense. Listen to a cassette tape about divers learning their lessons the hard way.

Hiccups and Other Sounds

Activity 14 Page 61

Do you know what causes hiccups? Why you yawn? How laughing and crying are alike? You'll get some interesting and useful information about your breathing system in this excursion.

Ways of Getting Oxygen

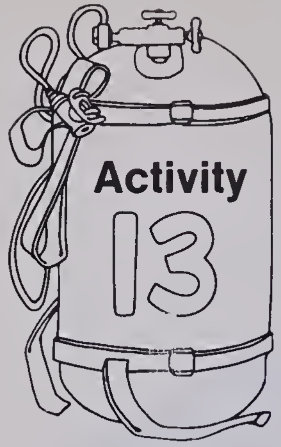
Activity 15 Page 67

Animals aren't the only ones who breathe. Even plants do it! Find out in this excursion how plants, frogs, fish, and worms get their oxygen.

Death by Drowning

Activity 16 Page 73

Drowning is a major cause of accidental deaths. There are many ways to drown, even without getting any water in your lungs. Learn about drowning in this excursion.



MATERIALS PER STUDENT UNIT

cassette tape for *Getting Enough Oxygen;* cassette player, preferably with headphones

Optional: air piston, such as medical syringe, with cap; carbonated liquid, such as soda water, ginger ale, or cola

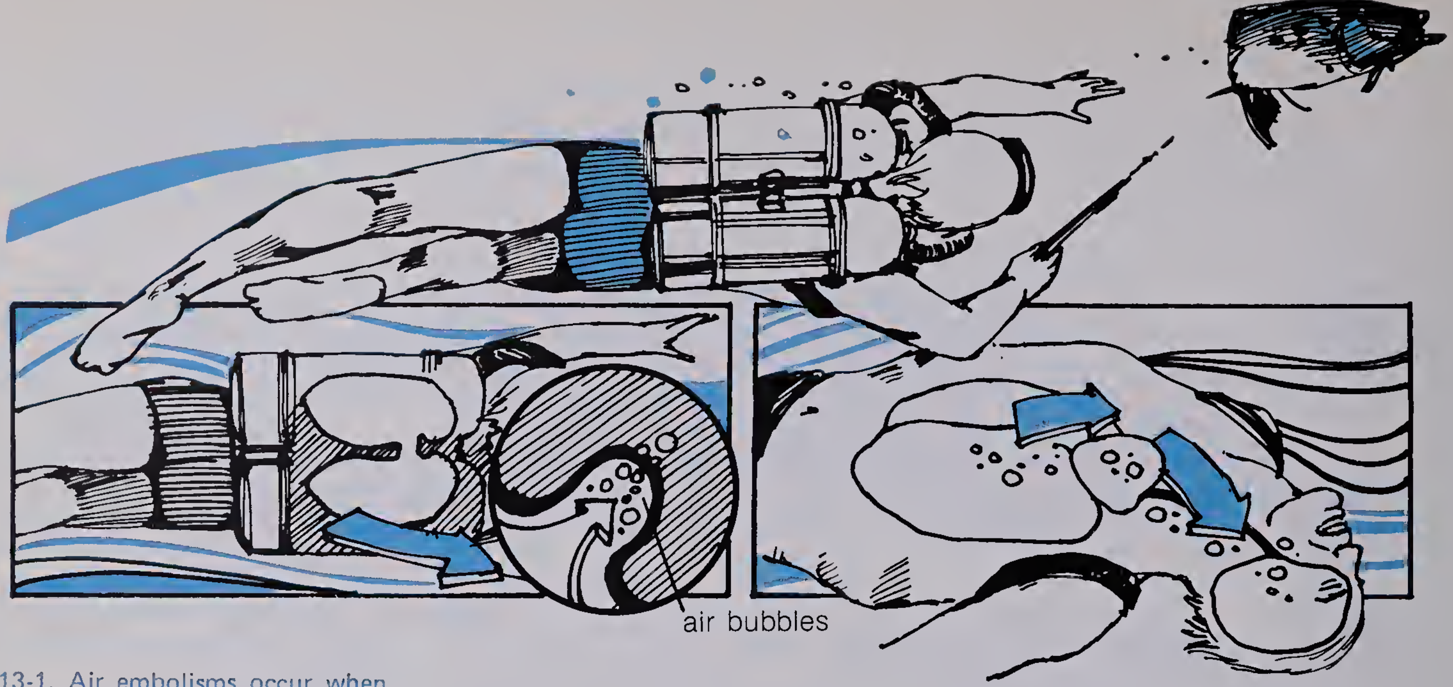
Overcoming Diving Problems

ACTIVITY EMPHASIS: The causes, effects, and prevention of air embolism and the bends.

It may seem strange, but getting enough oxygen while underwater is not a major diving problem. Diving suits and compressed-air pumps and tanks give divers all the oxygen they need. The real problems, such as breathing compressed air, are related to the large pressures found underwater.

Listen now to a modern-day tale about some diving problems. Get a cassette player and the tape for *Getting Enough Oxygen.* Listen to the band for Activity 13. The following illustrations go along with the story.

An investigation on recompression is suggested on the tape, using the materials listed as optional under Materials per Student Unit.

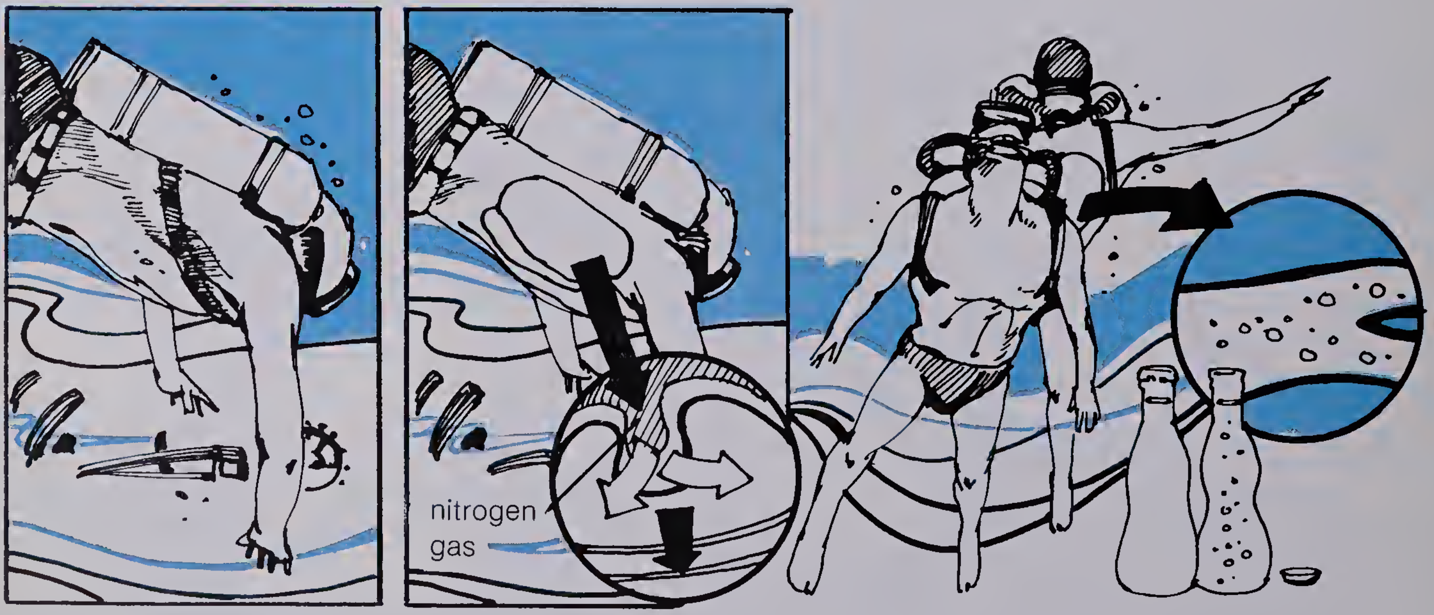


13-1. Air embolisms occur when divers inhale air at great pressure and then rise to lower pressures without exhaling. Expanding air goes through alveoli and bubbles into the bloodstream. Air bubbles block further blood transport; blood deficiency in brain causes convulsions. Prevention: Exhale expanding air while rising.

Boyle's Law: When the pressure on a gas decreases, the volume of the gas increases.

Prevention: Breathe out while surfacing. Don't hold your breath!

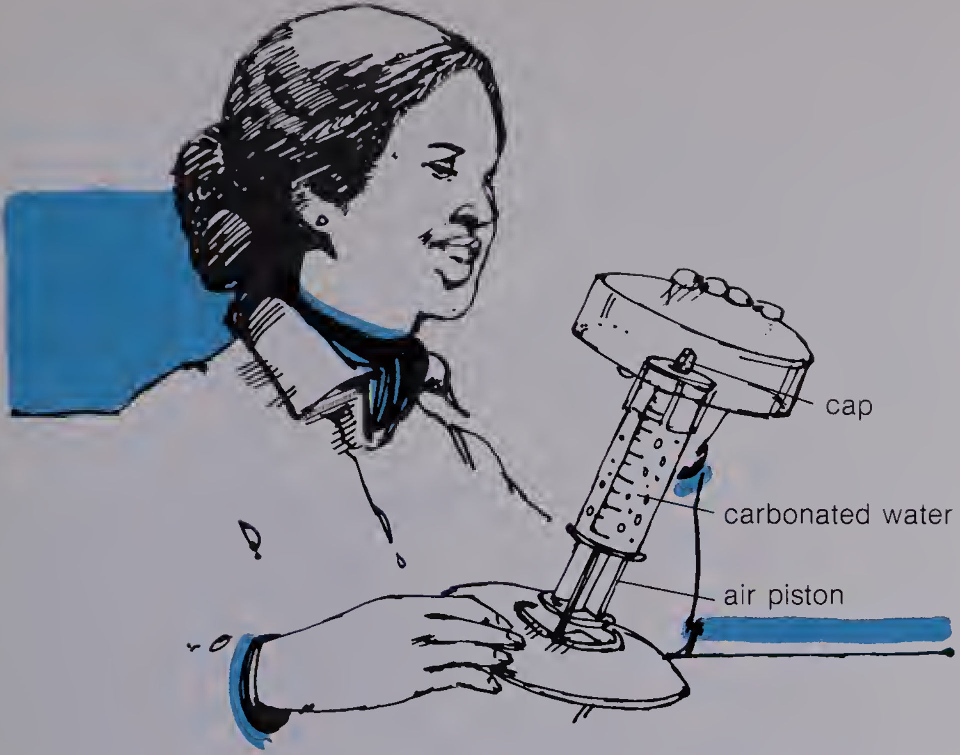
★ 13–1. Explain what causes air embolism and how the problem can be prevented.



13-2. Painful condition due to presence of bubbles of nitrogen gas in bloodstream. At depth, extra nitrogen dissolves in diver's body. If diver rises too fast, pressure is released too fast, and the nitrogen gas bubbles before it can be exhaled normally. Prevention: Stop ascent periodically to let excess dissolved nitrogen escape through the lungs.

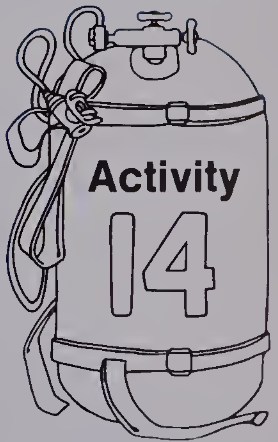
Prevention: Make the necessary decompression stops while returning to the surface.

★ 13–2. What are the bends? What causes the bends and how can they be prevented?



★ 13-3. How does being put in a recompression chamber cure the bends?

13-3. High pressure forces nitrogen gas bubbles to redissolve in diver's body. Pressure is then slowly brought back to 1 atm, allowing the released nitrogen to escape through the lungs.



Hiccups and Other Sounds

MATERIALS PER STUDENT UNIT
cassette tape for *Getting Enough Oxygen*
cassette player, preferably with headphones

ACTIVITY EMPHASIS: How the breathing system produces hiccups and is used to cry, laugh, yawn, sob, and sigh.

You do a lot more with your breathing system than just move air in and out. You use it to express emotions when you laugh, cry, yawn, sob, or sigh.

You keep the system open by coughing and sneezing. And your breathing system is responsible for your hiccups.

The world's record for hiccuping? A man who hiccuped over 160 million times in eight years, with just one week's rest. Over 60,000 "cures" were tried on him. They say it was a prayer that finally worked.

See if you can figure out what happens inside you during a hiccup. Touch your throat with one hand and your upper abdomen with the other hand. Make a hiccup.

✓ 14–1. What could you feel in your throat?
14-1. Muscles move and vibrations are felt.

✓ 14–2. What could you feel in your upper abdomen?
14-2. It moves in quickly.

What you felt in your abdomen was due to a sudden contraction, or spasm, of your diaphragm. What you felt in your throat was caused by your epiglottis closing over the trachea. And the noise you heard was air striking the top of the epiglottis as it closed.

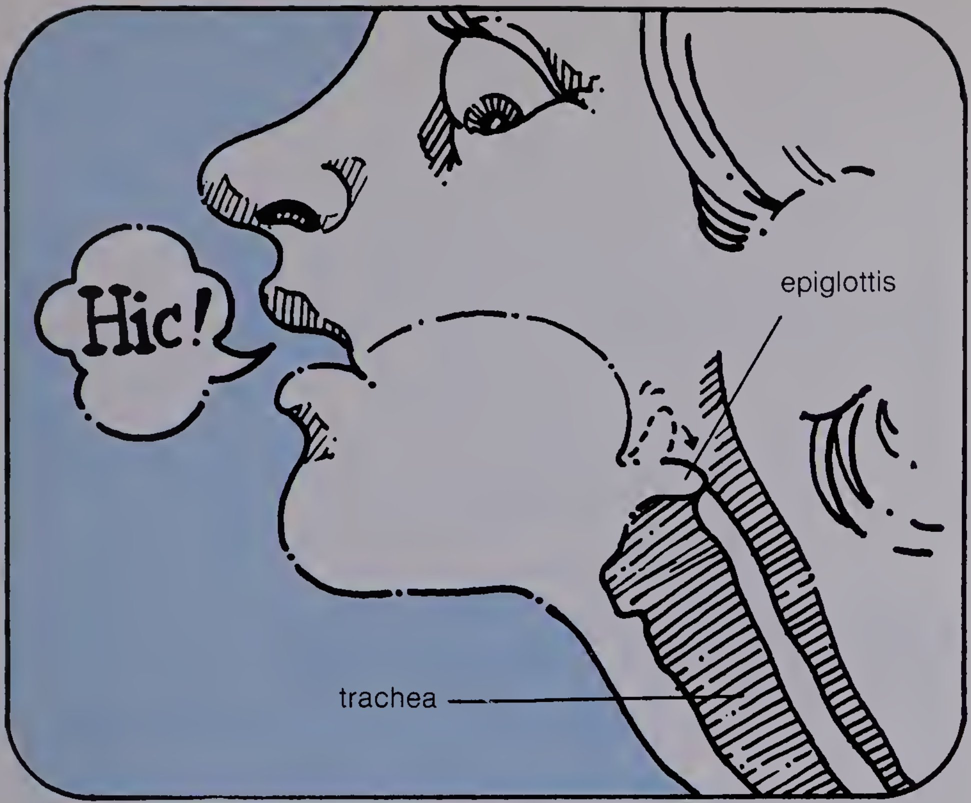
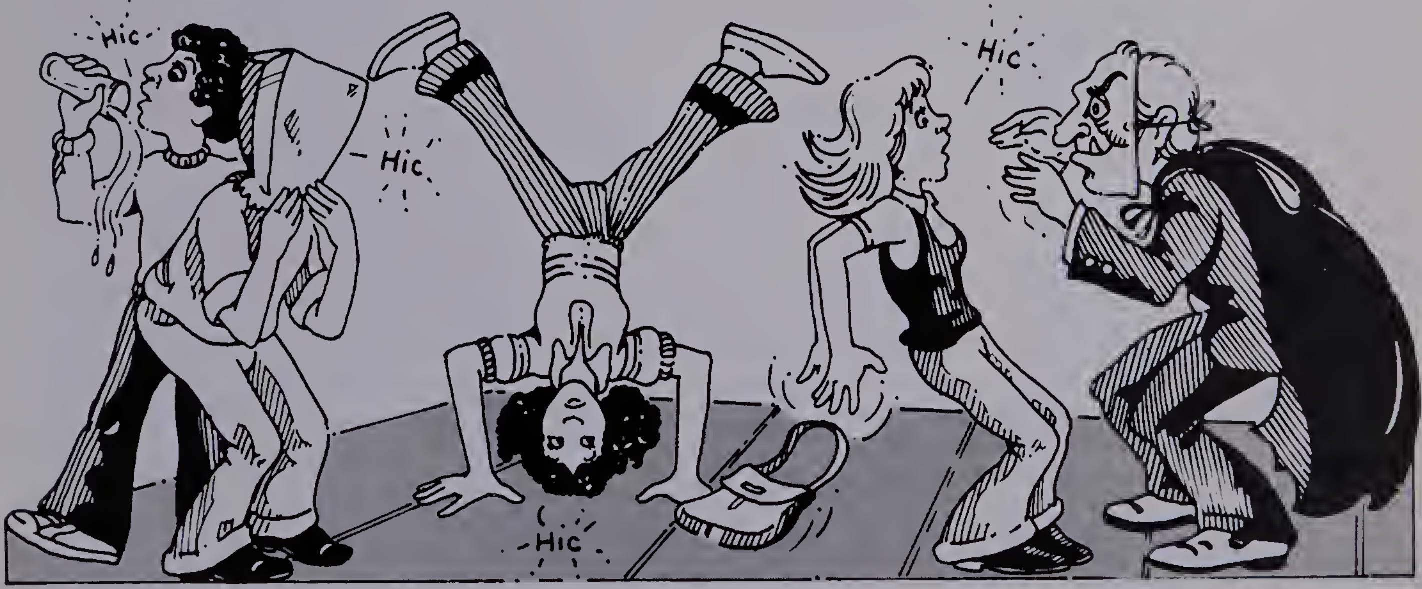


Figure 14–1

A true hiccup is begun by a spasm of the diaphragm. There is a sudden inspiration, or intake of air, followed quickly by a closing of the epiglottis. The sudden stoppage of air flow causes the *hic* sound (Figure 14–1). Hiccuping is involuntary, a reflex you can't control even if you try.



✓ 14–3. What are some cures you've heard about for hiccups?

14-3. Answers will vary. Some "cures" are drinking water, putting cold packs on the abdomen, holding one's breath, swallowing sugar, breathing into a paper bag, and being scared by someone.

14-4. The CO_2 level increases.

✓ 14–4. What happens to the amount of carbon dioxide (CO_2) in your blood when you breathe into a paper bag or hold your breath? (See Activity 7 if you need to refresh your memory.)

14-5. If the CO_2 level is higher, breathing rate increases. If the CO_2 level is lower, breathing rate decreases.

✓ 14–5. When the level of CO_2 in your blood changes, how does the breathing center in your brain respond?

14-6. A higher CO_2 level in the blood increases the breathing rate. This might somehow control the involuntary diaphragm spasm.

★ **14–6. Based on your answers to Questions 14–4 and 14–5, how might breath-holding or bag-breathing stop the hiccups?**

Another way to get rid of the hiccups might be to drink a glass of warm water or to put a cold pack on the abdomen. These methods tend to relax the diaphragm.

Coughing & Sneezing

Both coughing and sneezing consist of an inspiration followed by a forceful expiration. Basically the same internal body movement is involved, but the causes and effects are different.

14-7. Irritation to sneeze starts in the nasal passages. Irritation to cough starts in the pharynx, trachea, or bronchi.

✓ 14–7. Think about sneezing and coughing. Where does the irritation to sneeze start? To cough?

During a cough or sneeze, air is forced out of your nose or mouth at about 800 kilometres per hour! Along with that fast-moving air come droplets of moisture, possibly loaded with germs that could infect other people. That's why it's a good idea to cover your mouth or nose when you cough or sneeze.

Sighing & Yawning

Sighs and yawns both involve long and deep inspirations, followed by shorter expirations. All animals with backbones yawn, but no one is sure exactly why. It may be related to having low oxygen in the blood.

Yawning is said to be catching. See if you can make someone else yawn by yawning yourself. (Don't tell people what you're doing ahead of time or it won't be a true test.)

Sobbing, Crying & Laughing

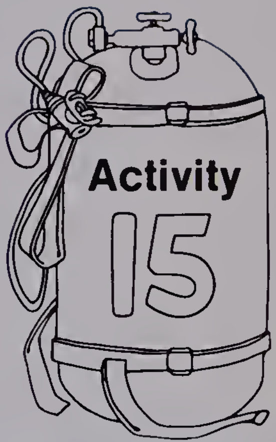
As far as breathing is concerned, sobbing and crying are two different things. During a sob, inspiration occurs in short bursts and the epiglottis closes over the trachea after each burst. After the lungs are full, the air is expired. During crying, a deep inspiration comes first, the trachea stays open, and the air is expired in short bursts.

Although the rhythm and sounds are usually quite different, laughing is very much like crying. In some people, it's hard to distinguish the two.

✓ 14–8. It is said that humans are the only animals that can laugh. If this is true, *why* do you suppose we laugh?

14-8. Answers will vary, but may include the idea that we have a "sense of humor."

Now get the tape for *Getting Enough Oxygen* and listen to the band for Activity 14. See if you can identify the various sounds produced by the breathing systems of different people.



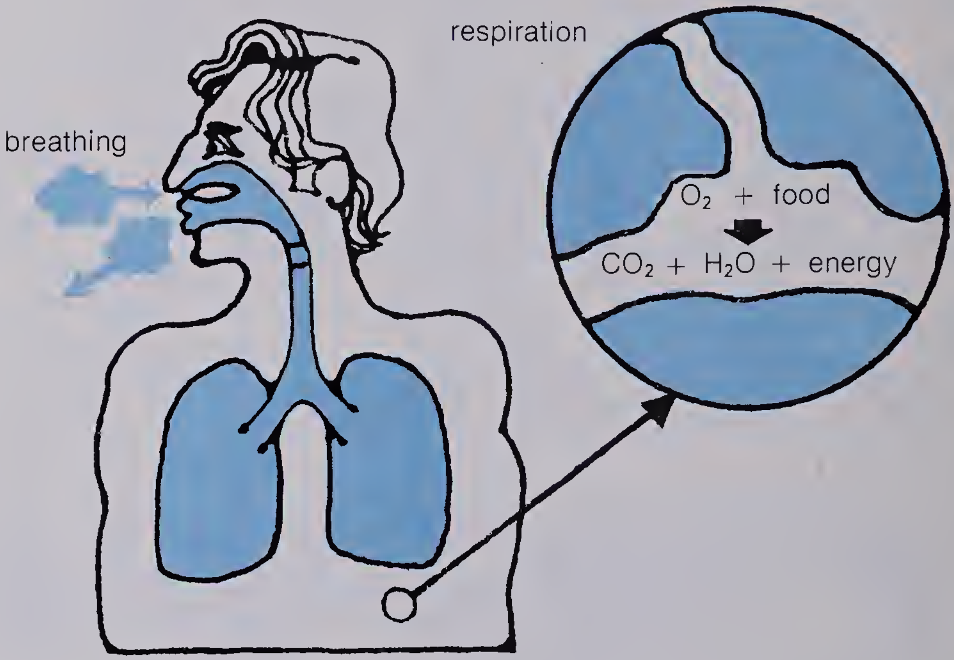
Ways of Getting Oxygen

ACTIVITY EMPHASIS: How organisms employ direct and indirect gas exchange in breathing.

Think about the huge variety of living things. You may be struck by how different they all seem. But living things are really alike in many ways.

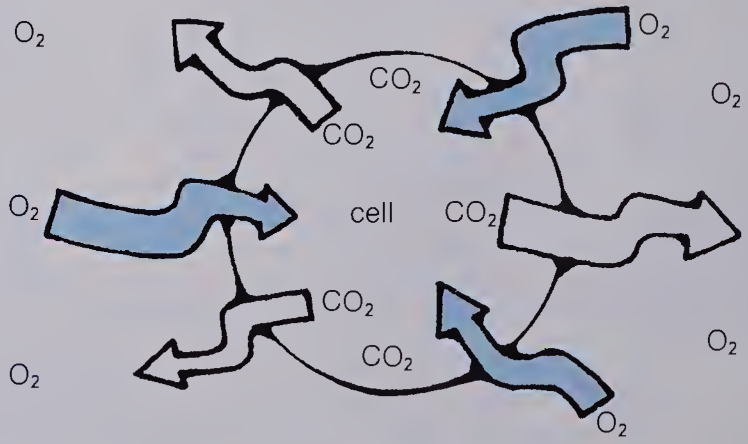
MATERIALS PER STUDENT UNIT
Resource Unit 12

One major similarity is that, by one method or another, almost all living things "breathe." Yes, even trees do it. You've studied your own breathing system, which differs from the systems of other living things. But the thing in common is that breathing gets oxygen into the organism. What the organism does with the oxygen is respiration.



Have *Resource Unit 12* available to aid students in understanding diffusion.

Breathing is the means by which living things get what they need to carry on respiration in their cells. And no matter what method of breathing it is, it depends on the process of diffusion to do the job. Breathing is a diffusion of oxygen (O_2) into cells and a diffusion of carbon dioxide (CO_2) out of cells.



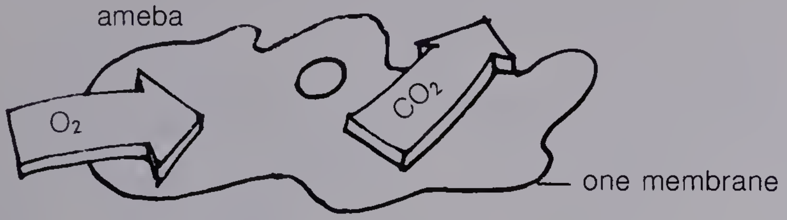
15-1. Molecules, always moving, tend to move away from areas of high concentration toward areas of low concentration.

★ **15-1. How does diffusion work?**

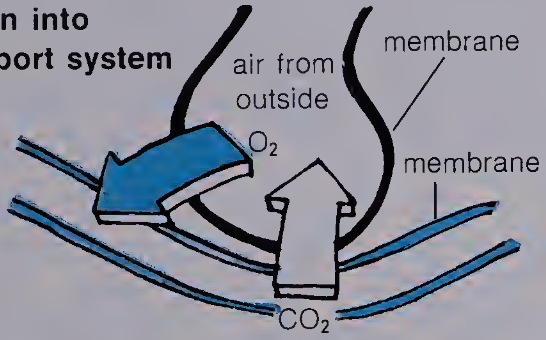
If you're not sure about your answer to that question, look at *Resource Unit 12* before going on.

When you get down to it, there are two main methods of breathing:

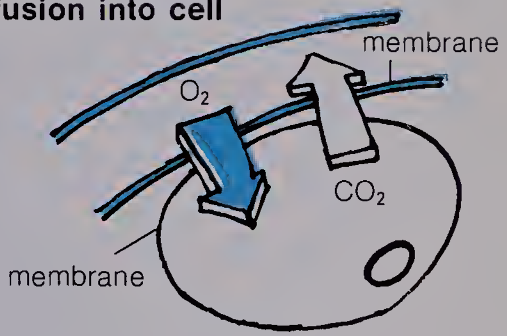
1. *Direct exchange* — where gas exchange between the cell and the "outside world" depends on diffusion across only one or two membranes, or walls only one cell thick.



2. *Indirect exchange* — where gas exchange depends on a gas transport system (like your blood), so there is diffusion across several membranes.



diffusion into blood transport system



diffusion into cell

Direct Exchange

Most living things breathe by a direct exchange of gases between their cells and the outside. This means that the cell membrane is the only wall to be diffused through. Such direct exchange is used by all green plants, by most one-celled organisms, and by many simple water-dwelling organisms.

Oxygen in the surrounding air or water diffuses directly into the cells. Carbon dioxide in the cells diffuses directly into the air or water.

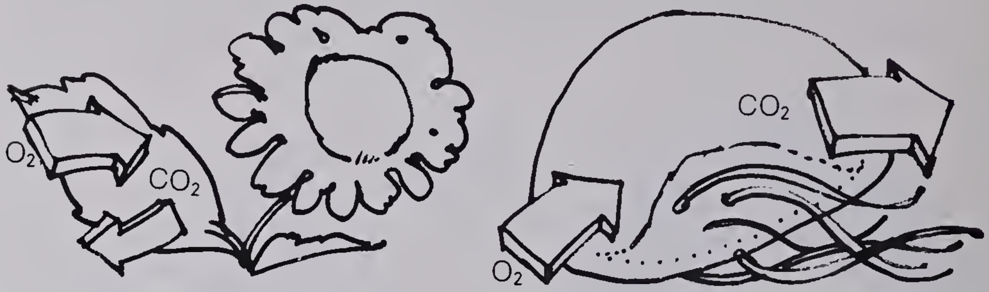


Figure 15–1

✓ 15–2. What part of a plant does the breathing?

15-2. The leaves.

If available, dissected specimens such as a grasshopper, crayfish, fish, and frog will interest students and help with comparison observations.

Insects and a few other types of small animals have specialized air-tube systems for exchanging O_2 and CO_2. Holes called *spiracles* in the tiny animal's body wall open into the air-tube system. The spiracles on a grasshopper are easy to see.

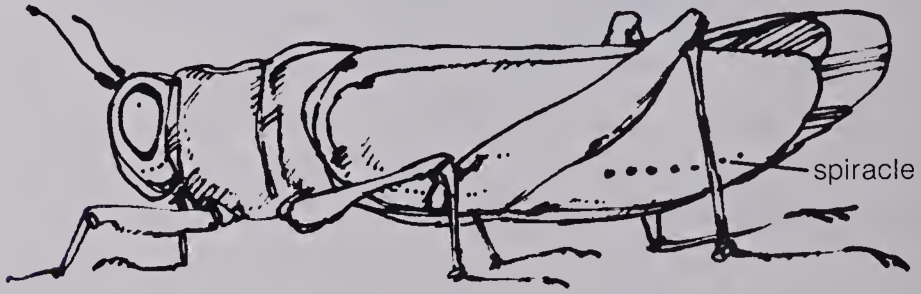
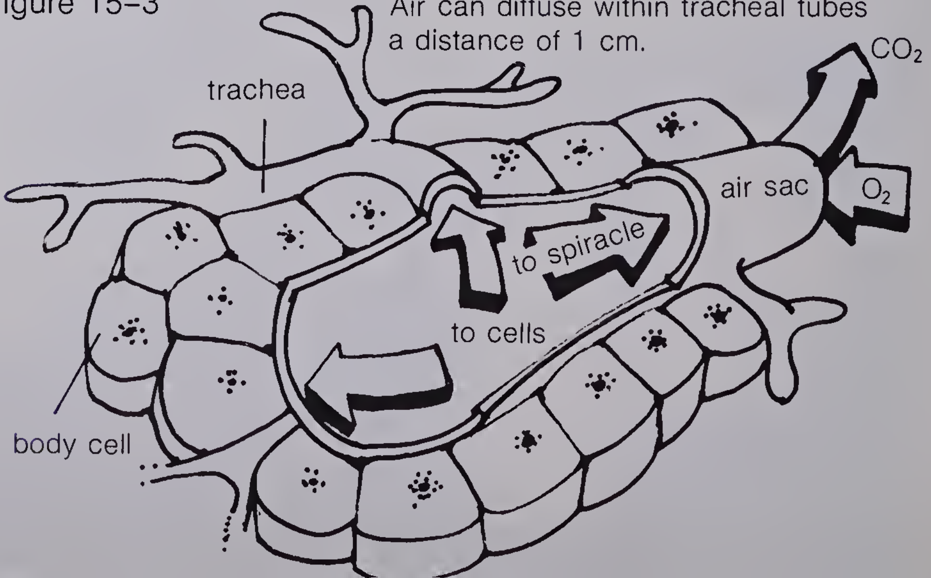


Figure 15–2

When air flows through the spiracles, it enters cavities called *air sacs*. Leading from the air sacs are tracheal tubes, which lead to all the cells in the animal's body. At the cells, O_2 diffuses in and CO_2 diffuses out.

Figure 15–3



The animal contracts and expands its abdomen, much as you do when you try to "hold your stomach in" and then let it out again. The motion of the animal's abdomen acts as a sort of pump to keep the air inside it moving through the air passages.

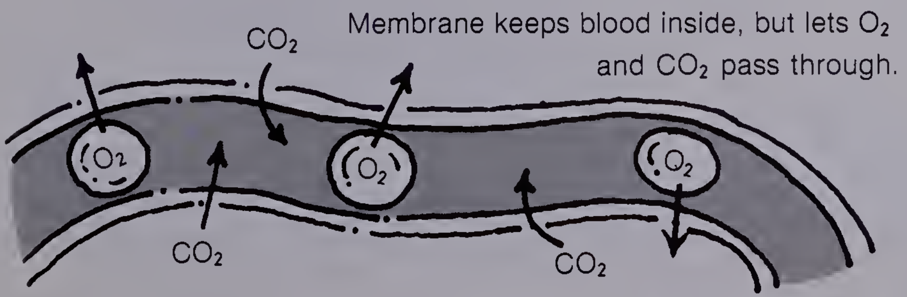
This type of breathing system limits insects to their small size. The system is just not very efficient. The pumping action of the abdomen can't move a lot of air, and diffusion through the tracheal walls is slow. For the system to work, each cell has to be within a centimetre of an air sac in order to get enough oxygen.

✓ 15–3. Why would an ant 3 metres tall have trouble taking over the world? (Hint: Consider its breathing system.)

15-3. Not all the giant ant's cells would be within a centimetre of its air sacs. The primitive pumping action of its breathing system and the slow diffusion of oxygen within the tracheae would not provide enough oxygen to the cells. The ant would die from lack of energy through respiration.

Indirect Exchange

Once animals reach a certain size, direct air passage to cells through tracheal tubes does not provide enough oxygen. So in larger animals, a blood system is needed to transport O_2 and CO_2. The gases must now diffuse through a membrane into the blood.



CO_2
Membrane keeps blood inside, but lets O_2 and CO_2 pass through.
O_2
O_2
O_2
CO_2
CO_2

The simplest kind of indirect exchange occurs in animals that breathe through their skins. Earthworms, for example, are skin breathers (Figure 15–4). Their blood system is right next to their thin, moist skin. O_2 can enter the blood easily and CO_2 can leave easily.

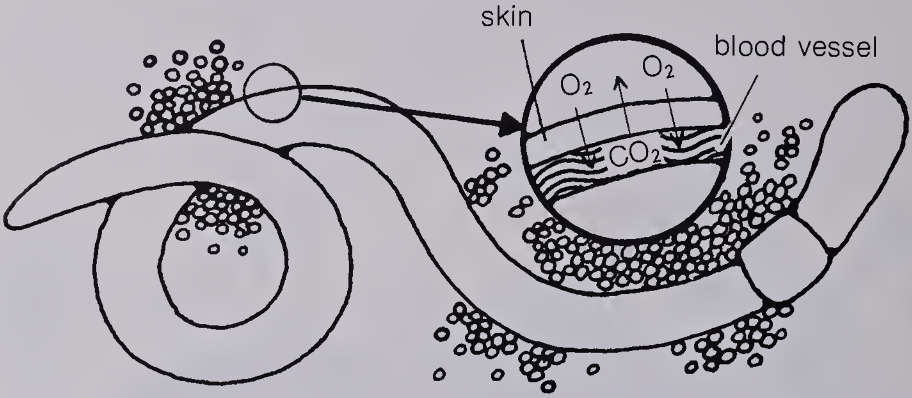


Figure 15–4

✓ 15–4. What is it about an earthworm's breathing system that limits where the earthworm can live?

15-4. The system requires a moist skin for proper gas diffusion. An arid environment would dry out the skin. (And in too moist an environment, the earthworm could drown.)

Many water animals such as fish, clams, and lobsters have membrane surfaces called *gills*. Gills offer a large area of membrane surface for gas exchange with the surrounding water. Gills are very delicate membranes and are usually protected inside the body of the animal. So instead of the gills waving out into the water, the water is taken inside the animal and passed over the gills (Figure 15–5). Blood circulating through the gills picks up O_2 and gets rid of CO_2.

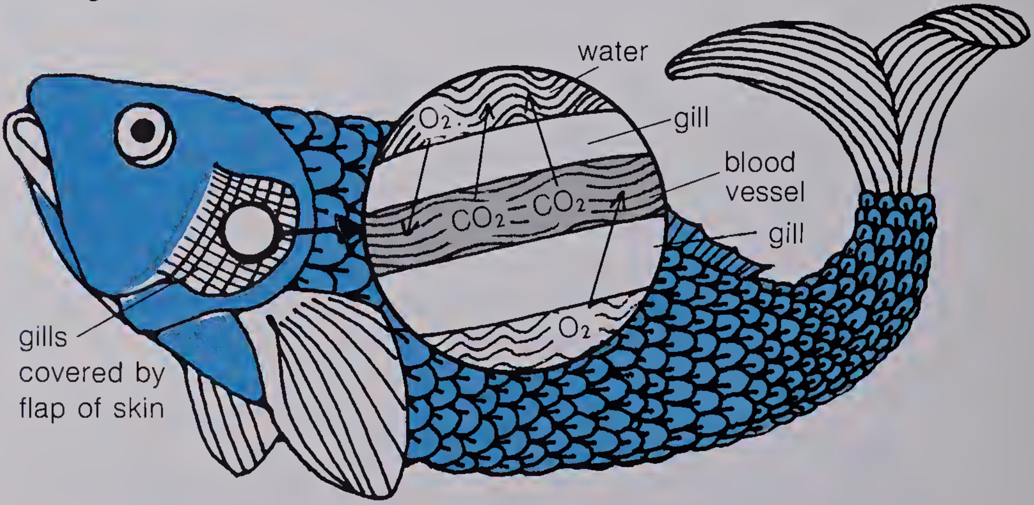


Figure 15–5

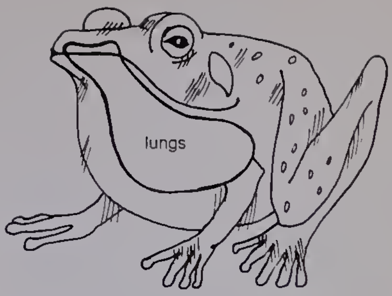
✓ 15–5. Why do you suppose many fish would die if they didn't keep swimming?

15-5. Water would cease to pass over the gills. The fish would die from a buildup of carbon dioxide and a lack of oxygen.

Still larger animals (birds, reptiles, amphibians, and mammals) have lungs to exchange gases. Like gills, lungs are made up of many delicate membranes and are protected inside the body.

Different types of lunged animals use different methods to get air into their lungs. You might find it interesting sometime to watch a frog breathe; see if you can figure out how it gets the air in. The frog's method is quite different from yours.

Whatever breathing system an organism uses, the job is the same: Bring O_2 to the cells and take CO_2 away.

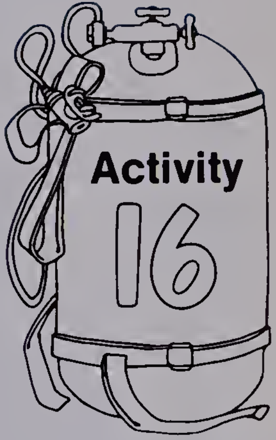


★ **15-6. In what ways does breathing differ among different organisms?**

15-6. Answers should include ideas of direct and indirect exchange. Other differences might be noted.

★ **15-7. How is breathing similar in different organisms?**

15-7. Breathing provides cells with O_2 gas and takes away the waste gas CO_2.



Death by Drowning

ACTIVITY EMPHASIS: The causes of death by drowning; first-aid techniques for drowning victims.

MATERIALS PER STUDENT UNIT
None.

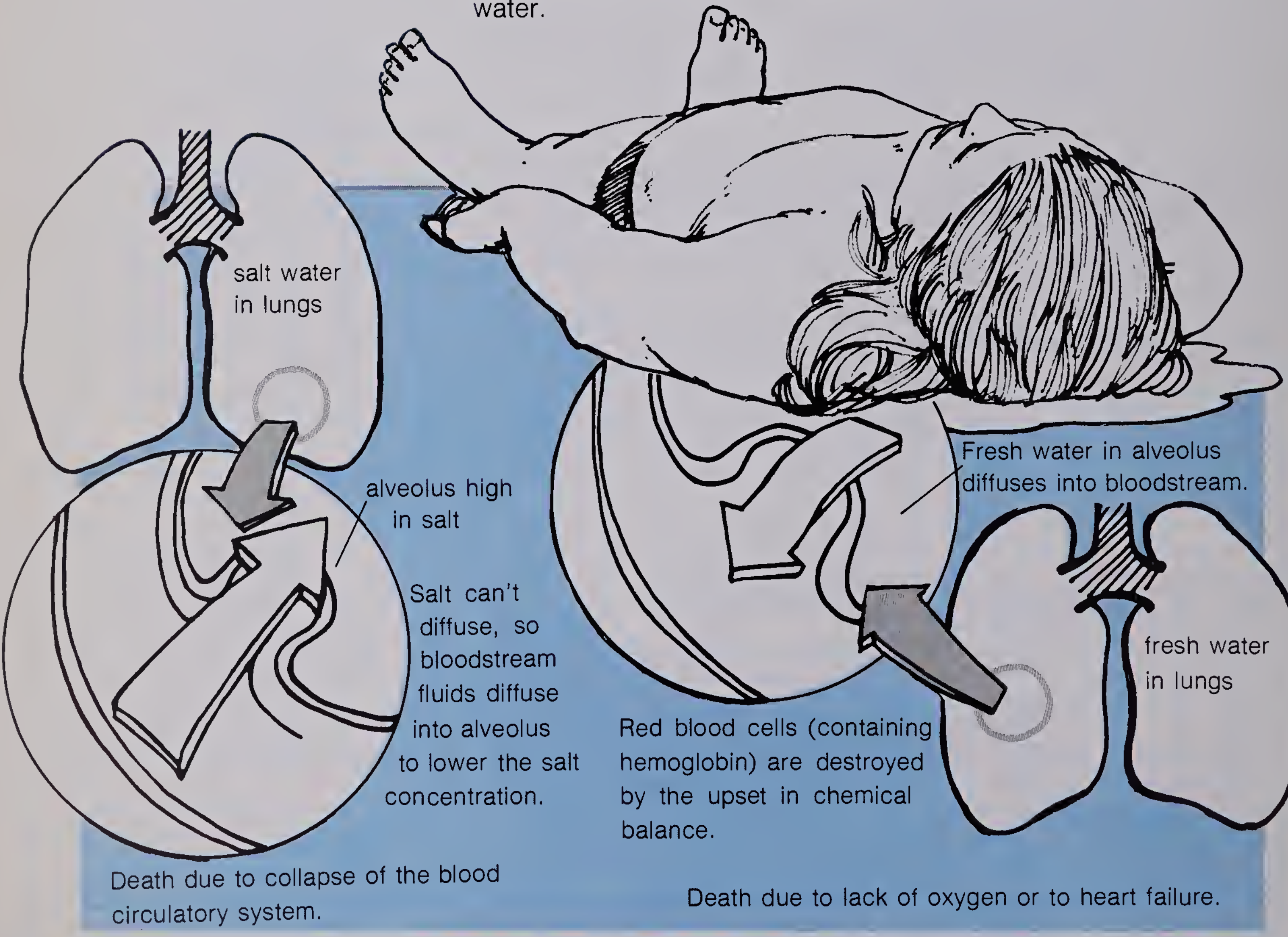
Drowning is the fourth leading cause of accidental deaths in the United States. (The top three are automobile accidents, falls, and fire and explosions.) Drownings can occur when people are swimming, boating, or just taking baths. People, while drunk, have even drowned in their own vomit.

During drowning, the victim may be swallowing water or taking water into the lungs, or both. This makes the victim heavier, so if the person is in a body of water, he or she may sink. Without oxygen, unconsciousness and death soon follow.

✓ 16–1. State a reason why even good swimmers should wear life preservers while boating.

16-1. A person may be knocked unconscious by a boating accident and not be able to swim or float. A life preserver will keep an unconscious person afloat.

"Death by drowning" is a general phrase that is applied to many deaths where lack of oxygen is a factor. The actual cause of death can differ with the situation. Drowning in salt water, for instance, causes death differently than does drowning in fresh water.


salt water
in lungs
alveolus high
in salt
Salt can't diffuse, so bloodstream fluids diffuse into alveolus to lower the salt concentration.
Death due to collapse of the blood circulatory system.
Fresh water in alveolus diffuses into bloodstream.
fresh water
in lungs
Red blood cells (containing hemoglobin) are destroyed by the upset in chemical balance.
Death due to lack of oxygen or to heart failure.

A person may even drown with little or no water taken in. Under certain conditions, such as pain, fear, or diving into very cold water, the larynx undergoes a reflex spasm. The spasm contracts the larynx, so the trachea is closed off. The victim cannot breathe and dies from a lack of oxygen.

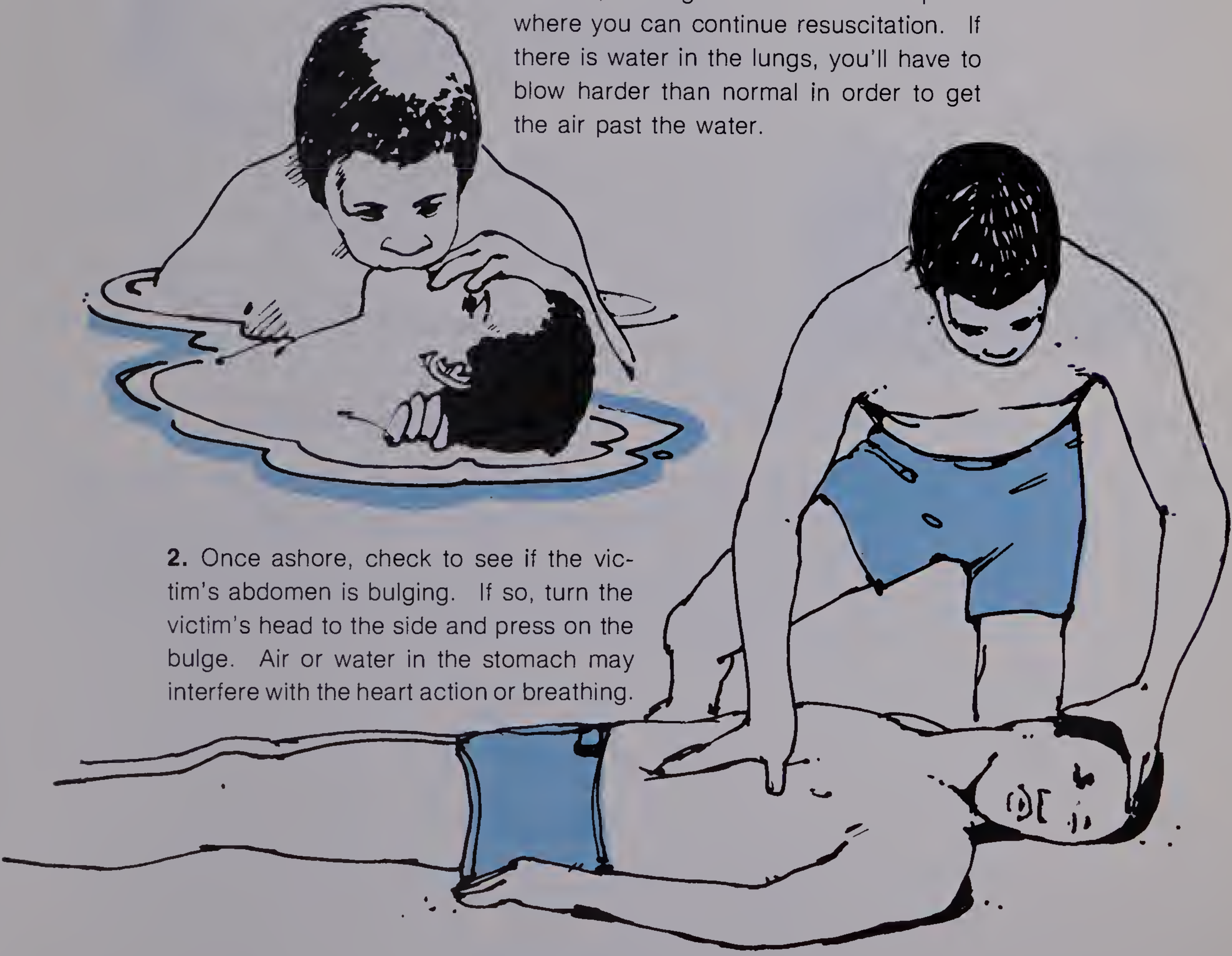
Hyperventilation may result in drowning. If the involuntary breathing control system fails to work after hyperventilation, the victim fails to breathe and becomes unconscious. Unconscious, the victim breathes water.

✓ 16–2. How does hyperventilation "fool" the involuntary breathing control system? (Hint: See Activity 7.)

16-2. Hyperventilation lowers the level of CO_2 in the blood. The oxygen supply in the lungs may be used up before the breathing control center triggers breathing again.

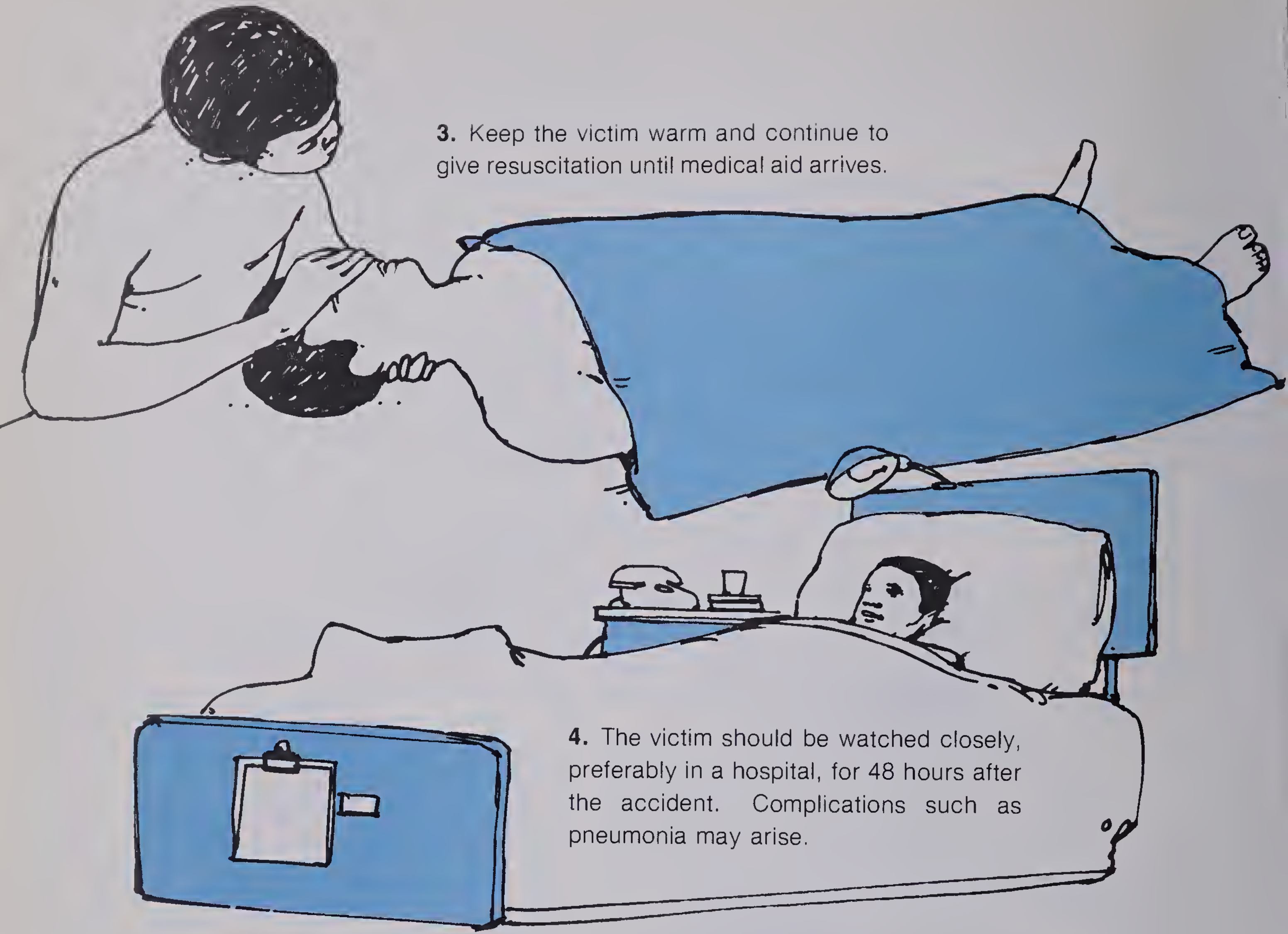
First Aid

If you ever try to save a drowning victim, you must act quickly; the victim could die within 10 minutes. It's not possible to pour water out of the victim's lungs, so don't attempt to do so. The procedure is the usual mouth-to-mouth resuscitation technique with a few variations.



1. Inflate the victim's lungs with 10 quick breaths, then get the victim to a place where you can continue resuscitation. If there is water in the lungs, you'll have to blow harder than normal in order to get the air past the water.

2. Once ashore, check to see if the victim's abdomen is bulging. If so, turn the victim's head to the side and press on the bulge. Air or water in the stomach may interfere with the heart action or breathing.



3. Keep the victim warm and continue to give resuscitation until medical aid arrives.

4. The victim should be watched closely, preferably in a hospital, for 48 hours after the accident. Complications such as pneumonia may arise.

16-3. Whether drowning occurs because of water in the lungs or a laryngeal spasm, death results due to a lack of oxygen reaching the body's cells. (Salt water in the lungs causes a collapse of the circulatory system, but it's the circulatory system that gets oxygen to the cells.)

★ 16–3. Explain how drowning kills a person.

A situation similar to drowning can occur when a person swallows turpentine or a petroleum product such as gasoline. Vomiting these substances out of the digestive tract can cause fumes and even liquid to get into the lungs. The lungs become coated with the oily substance, cutting off the normal flow of oxygen. The victim dies from a lack of oxygen.

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The ISIS Project is an intricate effort involving many people in many roles. The following individuals have made significant contributions to that effort.

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